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A MECHANICAL HARMONIC SYNTHESIZER-ANALYZER.

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ABSTRACT.

A harmonic synthesizer is described that has thirty harmonic elements (fifteen sine components and fifteen cosine components) that operate simultaneously, and the sum of the thirty sinusoidal movements is recorded by a tracing point (pencil) on a drawing board that is driven uniformly past the pencil point.

Analysis is accomplished by setting the amplitudes of the thirty elements to values that are determined from the values of selected ordinates from the curve to be analyzed, and the harmonic components of this curve are determined from selected ordinates of the auxiliary curve that is traced by the machine. Thirty-two equispaced ordinates from the curve to be analyzed furnish sufficient data whereby analysis is accomplished, by a single trace of the machine, that includes fifteen harmonic components (fifteen sine components and fifteen cosine components); or, sixty-four equispaced ordinates may be taken from the curve and the analysis will include thirty-one harmonic components that are obtained from two traces made by the machine (odd harmonics are determined from one auxiliary curve and even harmonics from the other curve); or, one hundred-and-twenty ordinates may be selected from the curve and the analysis is extended to fifty-nine harmonic components by tracing four auxiliary curves with the machine.

Wave synthesis and wave analysis have been of theoretical and practical interest to mathematicians, physicists and engineers since the outstanding contributions of Fourier [1] in 1822. The solution of many problems in sound, electric waves,

[1] J. B. L. Fourier, "La Theorie Analytique de la Chaleur," Paris.

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electrical vibrations and mechanical vibrations depend upon the harmonic analyses of complex wave forms or the syntheses of complex waves from sinusoidal components.

The schemes that have been proposed and the electrical and mechanical methods that have been devised to aid in the processes of analysis and synthesis are so numerous that no attempt will be made to enumerate them. However, two machines have been built that warrant special mention on account of their mechanical perfection and the range of their multiple frequency components. One of these machines is the Henrici analyzer with thirty spherical integrators which was built for Professor D. C. Miller [2] at Case School of Applied Science, and the other machine is the synthesizer with forty harmonic components that was designed and built by Mr. B. E. Eisenhour [3] at Riverbank Laboratories.

The machine which is to be described herein is fundamentally a synthesizer with fifteen sine components and fifteen cosine components. The multiple ratios of the sinusoidal motions are accomplished with a train of gears of the proper ratios and the summation is accomplished by a chain and pulleys in much the same manner as is done in the tide predictor.[4] The amplitude of each sine and of each cosine component may be set independently and all thirty of the sinusoidal motions are communicated simultaneously to the chain. The sum of the harmonic motions is the resultant motion of the endless chain that causes a pencil point to move in a vertical line, the pencil being fastened to a weight that is suspended from the chain. By means of a gear, rack and pinion a drawing board (in a vertical plane) is moved uniformly in a horizontal direction past the pencil point.

All parts of this machine were built on a large scale with the idea that greater precision would be had and, also, that it would be more economical to construct a large machine that is rugged and dependable even though the mechanism is rather complicated. The complete machine weighs nearly a ton; it is about fifteen feet long and seven feet high.

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[2] D. C. Miller, JOUR. FRANK. INST., **182**, 285–322.

[3] Frederick W. Kranz, JOUR. FRANK. INST., **204**, 245–262.

[4] Special Publication No. 32, U. S. Coast and Geodetic Survey, Washington, D. C.

The machine is mechanically excellent and, as a synthesizer, it is capable of accurately constructing the resultant wave from fifteen specified harmonic components. However, the principal interest is in its application as an analyzer. Frederick W. Kranz [5] showed that a forty-element synthesizer could be used to analyze a given wave for the first thirty-nine harmonic components. It was also recognized that the Michelson and Stratton [6] machine with its eighty elements could be used as an analyzer.

The derivations that follow show the possibility of using a synthesizer, with comparatively few harmonic elements, to make analyses that include many harmonic components. Namely, a fifteen-element synthesizer is described which may be used to determine, easily and quickly from the tracing of a single auxiliary curve, the first fifteen harmonic components of a given wave form; or, it may be used to determine thirty-one harmonic components from the tracing of two auxiliary curves; or, it may be used to determine fifty-nine harmonic components from four auxiliary curves.

The major portion of this paper is devoted to the mathematical proofs and derivations of working equations, as well as demonstrations of test analyses of specified wave forms (by equations of waves), that are necessary to establish the possibilities of a fifteen-element harmonic synthesizer as an analyzer. The several test analyses are intended to outline the procedure that is to be followed in each of the three cases. Note that the first case involves approximate integration of $f(x) \cos nx\,dx$ (and $f(x) \sin nx\,dx$) by increments of 11.25° (or 30 instead of 32 equispaced ordinates may be chosen and then the increments would be 12°). The second case involves approximate integration by increments of 5.625° (or 60 instead of 64 equispaced ordinates may be chosen and then the increments would be 6°). The third case involves approximate integration by increments of only 3°.

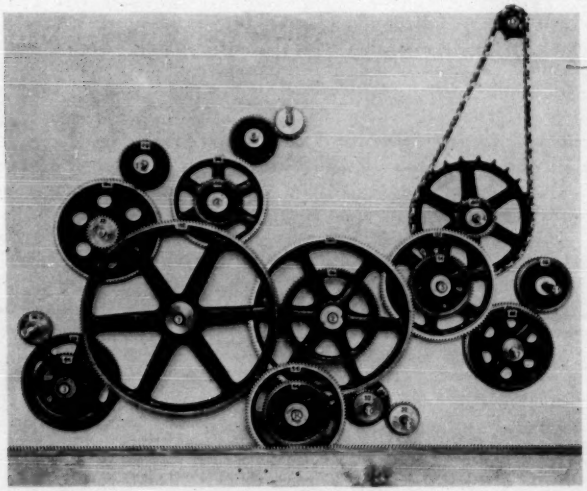
Details of the Machine. The driving mechanism is a train of twenty-two spur gears (shown in Fig. 1) that are high grade but selected from commercial stock. These gears drive fifteen shafts with rotational ratios ranging from one to

[5] Frederick W. Kranz, op. cit.

[6] Michelson and Stratton, *Am Jour. of Sci.*, **5**, 1–13.

fifteen. A Scotch crosshead is operated from each end of each shaft with the pin of each crosshead set in quadrature with the pin of the crosshead at the other end of the respective shaft. As the pin of each crosshead executes uniform circular motion it transmits sinusoidal motion to a vertical rod (in guides), and near the top of each vertical rod there is a small pulley over (or under) which passes a fine chain. The sum of the thirty sinusoidal motions is communicated to a tracer point

FIG. 1.

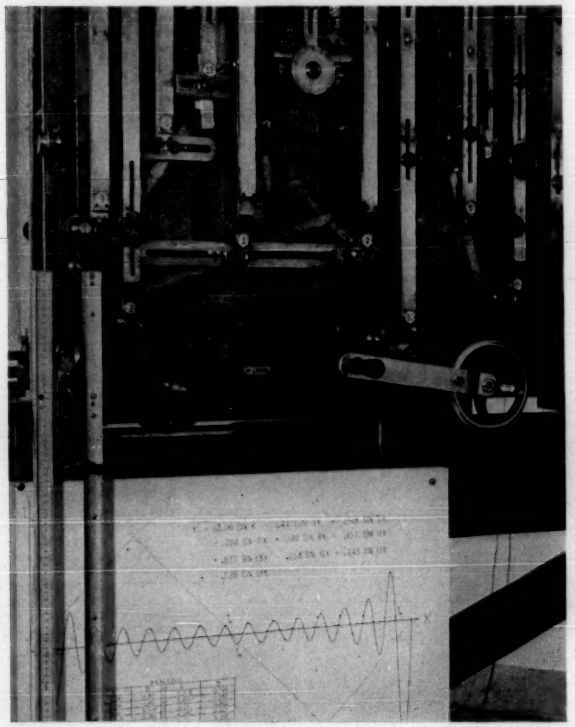


Train of gears.

(pencil) by means of the pulleys and the continuous fusee chronometer chain. The motion of the pencil point is in a vertical line and the pencil is carried by a metal block (in guides) that is suspended by the chain. By means of a rack and pinion, one shaft of the gear train drives the drawing board (in a vertical plane) with uniform horizontal motion past the pencil point. The rack is adjustable to different sized pinions and, thereby, the wave-length of the curve traced on the drawing board may be adjusted.

Figure 2 is a front view of the machine and it shows the eccentrics that furnish the fifteen sine components, the tracer block that is suspended by a loop of the endless chain around

FIG. 2.



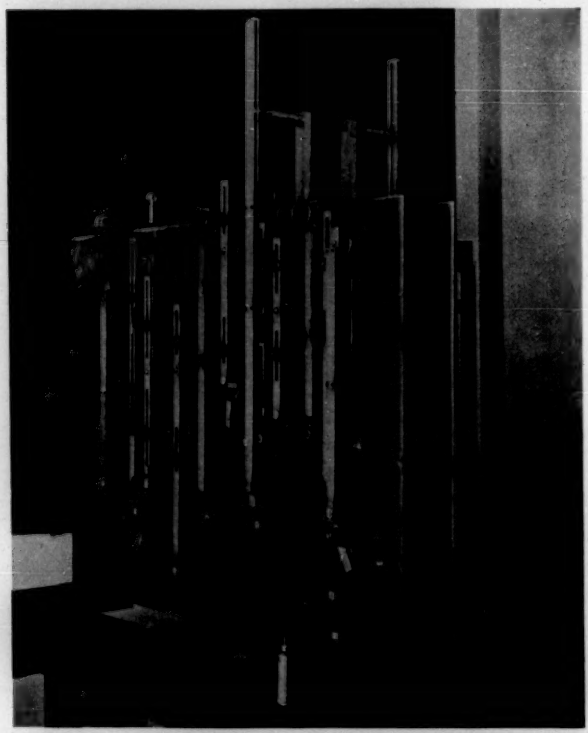
Front view—sine components.

a pulley on the block, the drawing board, and the crank by which the train of gears is driven.

Figure 3 is a back view of the machine and it shows the

eccentrics that furnish the fifteen cosine components. The chain threads around the pulleys on the vertical rods, it is transferred from front to back and from back to front over

FIG. 3.



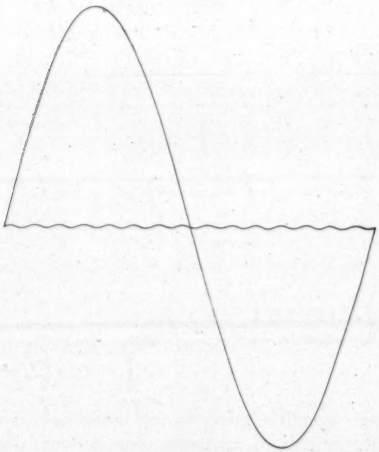
Back view—cosine components.

stationary pulleys, and tension is maintained in the continuous chain by the weight of the block that carries the tracing point. A more uniform tension is maintained through-

out the length of the chain by subjecting the entire machine to slight vibrations. The vibration of the machine is produced by a small electric motor with eccentric shaft and this method of reducing friction might be termed "mechanical lubrication."

The pin of each crosshead may be slid in either direction from a center-position on a crossbar and, thereby, positive or negative amplitudes are possible. The greatest amplitude that may be set on the fundamental is 16 cm. and the crossbar

FIG. 4.



Sensitivity test.

of a fifteenth element is long enough to permit amplitude settings of as much as 4 cm.

Syntheses. An example of the use of the machine as a synthesizer is shown by the zig-zag curve in Fig. 7 where the trace was made by adding the first fifteen harmonics of the Fourier series that represents a zig-zag periodic curve of straight-line sections. The rounded tops are evidence that the higher harmonics are missing.

Figure 4 shows a fundamental along with a fifteenth harmonic, both of them traced by the machine. The ampli-

tude of the fundamental is 10 cm. and the amplitude of the harmonic is only .5 mm., or the ratio of amplitudes is 200. The curves of Fig. 4 are given to show the mechanical perfection that has been attained and to indicate the sensitivity of the machine. An amplitude as small as .1 mm. is discernible by motion of the tracing point. The tracing point used to record the curves in this figure was a beam of light sharply focused on photographic paper.

Analyses. The possibilities of the synthesizer as an analyzer depend on two basic considerations. One of these basic facts is the repeating properties of sine and cosine functions such as

$$\sin x = \sin(\pi - x) = -\sin(\pi + x) = -\sin(2\pi - x), \quad (1)$$

$$\sin\left(\frac{\pi}{2} - x\right) = \sin\left(\frac{\pi}{2} + x\right) = -\sin\left(\frac{3\pi}{2} - x\right) = -\sin\left(\frac{3\pi}{2} + x\right), \quad (2)$$

and

$$\cos x = \cos(2\pi - x) = -\cos(\pi - x) = -\cos(\pi + x), \quad (3)$$

$$\cos\left(\frac{\pi}{2} - x\right) = -\cos\left(\frac{\pi}{2} + x\right) = -\cos\left(\frac{3\pi}{2} - x\right) = \cos\left(\frac{3\pi}{2} + x\right). \quad (4)$$

The other basic consideration which is utilized is the negative symmetry of the sum of multiple sine curves about the half-wave-length position and the positive symmetry of the sum of multiple cosine curves about the half-wave-length position.

In the derivations to follow the ordinates of the curve to be analyzed are always designated by the small letters (y_1, y_2, etc.), and the ordinates of the auxiliary curves that are traced by the machine are always designed by capitals (Y_1, Y_2, Y_1', etc.). The amplitude setting of the nth cosine component on the machine is designated by a_n, a_n' or by α_n, α_n', etc., while the amplitude setting of the nth sine component is designated by b_n, b_n' or by β_n, β_n', etc. The sum of the contributions from a series of multiple cosine components is abbreviated by C_1, C_2, or C_1', C_2', etc., and the sum of the

contributions from a series of multiple sine components is abbreviated by S_1, S_2, or S_1', S_2', etc.

THIRTY-TWO INCREMENTS.

$$A_n = \frac{2}{\lambda}\int_0^{\lambda} y \cos\frac{2\pi nx}{\lambda}\,dx, \tag{5}$$

$$\begin{aligned}
16\,A_1 &\doteq y_1\cos\frac{2\pi}{32}\cdots + y_{15}\cos\frac{30\pi}{32} - y_{16} \\
&\quad + y_{17}\cos\frac{34\pi}{32}\cdots + y_{31}\cos\frac{62\pi}{32} + y_{32} \\
&\doteq (y_1 + y_{31})\cos\frac{2\pi}{32} + (y_2 + y_{30})\cos\frac{4\pi}{32}\cdots \\
&\quad + (y_{15} + y_{17})\cos\frac{30\pi}{32} + y_{32} - y_{16} \\
&\doteq a_1\cos\frac{2\pi}{32} + a_2\cos\frac{4\pi}{32}\cdots \\
&\quad + a_{15}\cos\frac{30\pi}{32} + y_{32} - y_{16} \\
&\doteq C_1 + y_{32} - y_{16}, \qquad (6)
\end{aligned}$$

$$16\,A_2 \doteq a_1\cos\frac{4\pi}{32} + a_2\cos\frac{8\pi}{32}\cdots + a_{15}\cos\frac{60\pi}{32} + y_{32} + y_{16},$$

$$16\,A_2 \doteq C_2 + y_{32} + y_{16}, \qquad (7)$$

$$16\,A_3 \doteq C_3 + y_{32} - y_{16}, \qquad (8)$$

. . . . . .

$$16\,A_{15} \doteq C_{15} + y_{32} - y_{16}, \qquad (20)$$

$$a_1 = y_1 + y_{31}, \qquad (21)$$

$$a_2 = y_2 + y_{30}, \qquad (22)$$

$$a_3 = y_3 + y_{29}, \qquad (23)$$

$$a_4 = y_4 + y_{28}, \qquad (24)$$

$$a_5 = y_5 + y_{27}, \qquad (25)$$

$$a_6 = y_6 + y_{26}, \qquad (26)$$

. . . . . .

$$a_{15} = y_{15} + y_{17}, \qquad (35)$$

$$B_n = \frac{2}{\lambda}\int_0^{\lambda} y \sin\frac{2\pi nx}{\lambda}\,dx, \qquad (36)$$

$$16\,B_1 \doteq y_1 \sin\frac{2\pi}{32} \cdots + y_{15} \sin\frac{30\pi}{32} + 0$$

$$+ y_{17} \sin\frac{34\pi}{32} \cdots + y_{31} \sin\frac{62\pi}{32} + 0$$

$$\doteq (y_1 - y_{31}) \sin\frac{2\pi}{32} + (y_2 - y_{30}) \sin\frac{4\pi}{32} \cdots$$

$$+ (y_{15} - y_{17}) \sin\frac{30\pi}{32}$$

$$\doteq b_1 \sin\frac{2\pi}{32} + b_2 \sin\frac{4\pi}{32} \cdots + b_{15} \sin\frac{30\pi}{32}$$

$$\doteq S_1, \tag{37}$$

$$16\,B_2 \doteq b_1 \sin\frac{4\pi}{32} + b_2 \sin\frac{8\pi}{32} \cdots + b_{15} \sin\frac{60\pi}{32},$$

$16\,B_2 \doteq S_2$, (38) $\quad b_1 = y_1 - y_{31}$, (52)

$16\,B_3 \doteq S_3$, (39) $\quad b_2 = y_2 - y_{30}$, (53)

. . . . . $\quad b_3 = y_3 - y_{29}$, (54)

$16\,B_{15} \doteq S_{15}$, (51) $\quad b_4 = y_4 - y_{28}$, (55)

$$b_5 = y_5 - y_{27}, \tag{56}$$

$$b_6 = y_6 - y_{26}, \tag{57}$$

. . . . . .

$$b_{15} = y_{15} - y_{17}, \tag{66}$$

$$16\,(A_1 + B_1) \doteq C_1 + S_1 + y_{32} - y_{16} \doteq Y_1 + y_{32} - y_{16}, \tag{67}$$

$$16\,(A_1 - B_1) \doteq C_1 - S_1 + y_{32} - y_{16} \doteq Y_{31} + y_{32} - y_{16}, \tag{68}$$

$$A_1 \doteq \frac{1}{32}[Y_1 + Y_{31} + 2(y_{32} - y_{16}],$$

$$B_1 \doteq \frac{1}{32}[Y_1 - Y_{31}], \tag{69}$$

$$A_2 \doteq \frac{1}{32}[Y_2 + Y_{30} + 2(y_{32} + y_{16})],$$

$$B_2 \doteq \frac{1}{32}[Y_2 - Y_{30}], \tag{70}$$

$$A_3 \doteq \frac{1}{32}[Y_3 + Y_{29} + 2(y_{32} - y_{16})],$$

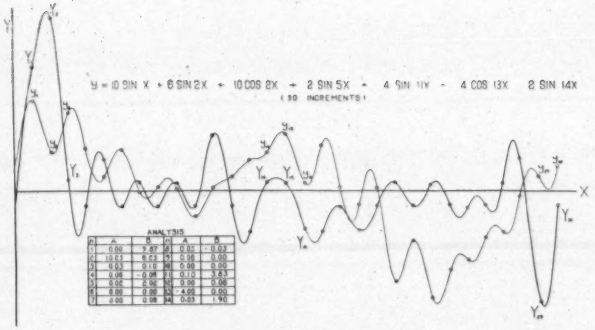
$$B_3 \doteq \frac{1}{32}[Y_3 - Y_{29}], \quad (71)$$

. . . . . .

$$A_{15} \doteq \frac{1}{32}[Y_{15} + Y_{17} + 2(y_{32} - y_{16})],$$

$$B_{15} \doteq \frac{1}{32}[Y_{15} - Y_{17}]. \quad (83)$$

FIG. 5.



Synthesis and analysis (increments of 12°).

Therefore, if the fifteen multiple cosine components of the synthesizer are set at the respective amplitudes as given by Eqs. 21–35 and the sine components are set at the respective amplitudes as given by Eqs. 52–66, the auxiliary curve with equispaced ordinates Y_1, Y_2, $\cdots$ Y_{32} is traced by the machine and the amplitudes of the fifteen harmonics of the curve which has equispaced ordinates y_1, y_2, $\cdots$ y_{32} are given by Eqs. 69–83. The auxiliary curve need not be actually traced since the values of Y_1, Y_2, etc. may be read from a stationary vertical scale. A dial on the shaft of the 8th multiple element indicates the angle through which the machine has been

turned; that is, Y_1 is read from the vertical scale when this dial shows one-quarter of a revolution, Y_2 when dial shows half a revolution, etc. Figure 5 shows the synthesis and the analysis of a curve represented by a specific equation for fourteen harmonics (increments of 12°).

SIXTY-FOUR INCREMENTS.

The analyses may be extended to thirty-one harmonics if the curve to be analyzed is divided into sixty-four equispaced ordinates (y_1, y_2, $\cdots y_{64}$), and a derivation similar to that used for thirty-two equispaced ordinates gives

$$64\,A_1 \doteq Y_1 + Y_{63} + 2(y_{64} - y_{32}), \tag{84}$$

$$64\,A_3 \doteq Y_3 + Y_{61} + 2(y_{64} - y_{32}), \tag{85}$$

$$64\,A_5 \doteq Y_5 + Y_{59} + 2(y_{64} - y_{32}), \tag{86}$$

. . . . . .

. . . . . .

$$64\,A_{31} \doteq Y_{31} + Y_{33} + 2(y_{64} - y_{32}), \tag{99}$$

and

$$64\,B_1 \doteq Y_1 - Y_{63} + 2(y_{16} - y_{48}), \tag{100}$$

$$64\,B_3 \doteq Y_3 - Y_{61} + 2(y_{48} - y_{16}), \tag{101}$$

$$64\,B_5 \doteq Y_5 - Y_{59} + 2(y_{16} - y_{48}), \tag{102}$$

. . . . . .

. . . . . .

$$64\,B_{31} \doteq Y_{31} - Y_{33} + 2(y_{48} - y_{16}), \tag{115}$$

where the auxiliary curve of equispaced ordinates Y_1, Y_2, $\cdots Y_{64}$ is traced by the machine with the amplitudes of the fifteen cosine components set at

$$a_1 = y_1 - y_{31} - y_{33} + y_{63}, \tag{116}$$

$$a_2 = y_2 - y_{30} - y_{34} + y_{62}, \tag{117}$$

. . . . . .

. . . . . .

$$a_{15} = y_{15} - y_{17} - y_{47} + y_{49}, \tag{130}$$

and the amplitudes of the fifteen sine components set at

$$b_1 = y_1 + y_{31} - y_{33} - y_{63}, \tag{131}$$

$$b_2 = y_2 + y_{30} - y_{34} - y_{62}, \tag{132}$$

. . . . . .

. . . . . .

$$b_{15} = y_{15} + y_{17} - y_{47} - y_{49}. \tag{145}$$

And the amplitudes of the even numbered components are given by

$$64\,A_2 \doteq Y_2' + Y_{62}' + 2(y_{64} - y_{48} + y_{32} - y_{16}), \tag{146}$$

$$64\,A_4 \doteq Y_4' + Y_{60}' + 2(y_{64} + y_{48} + y_{32} + y_{16}), \tag{147}$$

$$64\,A_6 \doteq Y_6' + Y_{58}' + 2(y_{64} - y_{48} + y_{32} - y_{16}), \tag{148}$$

. . . . . .

. . . . . .

$$64\,A_{30} \doteq Y_{30}' + Y_{34}' + 2(y_{64} - y_{48} + y_{32} - y_{16}), \tag{160}$$

and

$$64\,B_2 \doteq Y_2' - Y_{62}', \tag{161}$$

$$64\,B_4 \doteq Y_4' - Y_{60}', \tag{162}$$

$$64\,B_6 \doteq Y_6' - Y_{58}', \tag{163}$$

. . . . . .

. . . . . .

$$64\,B_{30} \doteq Y_{30}' - Y_{34}', \tag{175}$$

where the second auxiliary curve of equispaced ordinates $Y_1', Y_2', \cdots Y_{64}'$ is traced by the machine with the amplitudes of the fifteen cosine components set at

$$a_1' = y_1 + y_{31} + y_{33} + y_{63}, \tag{176}$$

$$a_2' = y_2 + y_{30} + y_{34} + y_{62}, \tag{177}$$

. . . . . .

. . . . . .

$$a_{15}' = y_{15} + y_{17} + y_{47} + y_{49}, \tag{190}$$

and the amplitudes of the fifteen sine components are set at

$$b_1' = y_1 - y_{31} + y_{33} - y_{63}, \tag{191}$$

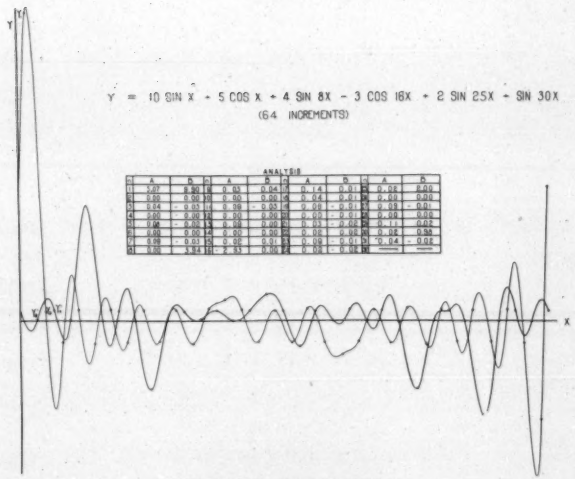
$$b_2' = y_2 - y_{30} + y_{34} - y_{62}, \tag{192}$$

. . . . . .

. . . . . .

$$b_{15}' = y_{15} - y_{17} + y_{47} - y_{49}. \tag{205}$$

FIG. 6.

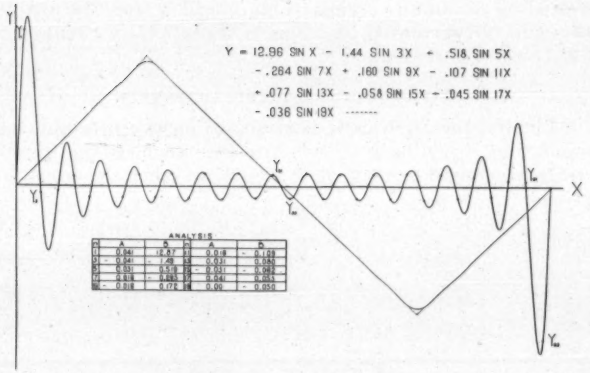


Analysis (increments of 5.625°).

If the curve is to be analyzed from sixty (increments of 6°), instead of sixty-four equispaced ordinates, only the first fourteen harmonic components of the machine are utilized ($a_{15} = a_{15}' = b_{15} = b_{15}' = 0$), and only thirty ordinates from each of the two auxiliary curves enter the calculations of the harmonic components of the curve that is being analyzed.

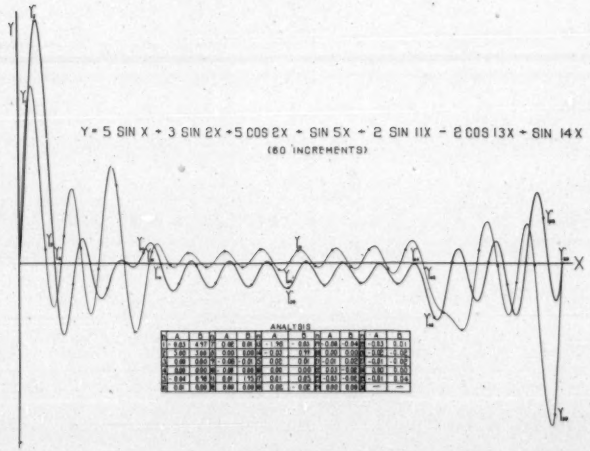
Figure 6 shows the analysis of a curve represented by a specific equation for thirty-one harmonics (increments of 5.625°). Figure 7 illustrates the determination of the first

FIG. 7.



Synthesis and analysis (infinite series).

FIG. 8.



Analysis (increments of 6°).

nineteen harmonics (odd numbered) of a curve that is represented by an infinite series. Figure 8 illustrates the analysis of a curve represented by a specific equation for twenty-nine harmonics (increments of 6°).

ONE HUNDRED-AND-TWENTY INCREMENTS.

Finally, the analysis is extended to include fifty-nine harmonics by dividing a curve into one hundred-and-twenty equispaced ordinates ($y_1, y_2, \cdots y_{120}$), and then the derivation gives

$$120\,A_1 \doteq Y_1 + Y_{119}' + 2(y_{120} - y_{60}), \quad (206)$$

$$120\,B_1 \doteq Y_1 - Y_{119}' + 2(y_{30} - y_{90}), \quad (207)$$

$$120\,A_3 \doteq Y_3' + Y_{117} + 2(y_{120} - y_{60}), \quad (208)$$

$$120\,B_3 \doteq Y_3' - Y_{117} + 2(y_{90} - y_{30}), \quad (209)$$

. . . . . .

. . . . . .

$$120\,A_{57} \doteq Y_{57} + Y_{63}' + 2(y_{120} - y_{60}), \quad (262)$$

$$120\,B_{57} \doteq Y_{57} - Y_{63}' + 2(y_{30} - y_{90}), \quad (263)$$

$$120\,A_{59} \doteq Y_{59}' + Y_{61} + 2(y_{120} - y_{60}), \quad (264)$$

$$120\,B_{59} \doteq Y_{59}' - Y_{61} + 2(y_{90} - y_{30}), \quad (265)$$

and

$$120\,A_2 \doteq Y_2'' + Y_{118}'' + 2(y_{120} + y_{60} - y_{30} - y_{90}), \quad (266)$$

$$120\,B_2 \doteq Y_2'' - Y_{118}'', \quad (267)$$

$$120\,A_4 \doteq Y_4''' + Y_{116}''' + 2(y_{120} + y_{60} + y_{30} + y_{90}), \quad (268)$$

$$120\,B_4 \doteq Y_4''' - Y_{116}''', \quad (269)$$

. . . . . .

. . . . . .

$$120\,A_{56} \doteq Y_{56}''' + Y_{64}''' + 2(y_{120} + Y_{60} + y_{30} + y_{90}), \quad (320)$$

$$120\,B_{56} \doteq Y_{56}''' - Y_{64}''', \quad (321)$$

$$120\,A_{58} \doteq Y_{58}'' + Y_{62}'' + 2(y_{120} + y_{60} - y_{30} - y_{90}), \quad (322)$$

$$120\,B_{58} \doteq Y_{58}'' - Y_{62}'', \quad (323)$$

where the four auxiliary curves of equispaced ordinates Y_1, Y_2, $\cdots$ Y_{120}; Y_1', Y_2', $\cdots$ Y_{120}'; Y_1'', Y_2'', $\cdots$ Y_{120}'' and Y_1''', Y_2''', $\cdots$ Y_{120}''' are traced by the machine with the amplitudes of the fifteen cosine components set at the respective values (α), (α'), (α'') and (α''').

(α)

$$\alpha_1 = a_1 + k_1 = (y_1 - y_{59} - y_{61} + y_{119}) + (y_{29} + y_{31} - y_{89} - y_{91}), \quad (324)$$

$$\alpha_2 = a_2 + k_2 = (y_2 - y_{58} - y_{62} + y_{118}) + (y_{28} + y_{32} - y_{80} - y_{92}), \quad (325)$$

. . . . . .

$$\alpha_{14} = a_{14} + k_{14} = (y_{14} - y_{46} - y_{74} + y_{106}) + (y_{16} + y_{44} - y_{76} - y_{104}), \quad (337)$$

$$\alpha_{15} = a_{15} + 0 = (y_{15} - y_{45} - y_{75} + y_{105}). \quad (338)$$

(α'')

$$\alpha_1'' = a_1' + b_1' = (y_1 + y_{59} + y_{61} + y_{119}) + (-y_{29} - y_{31} - y_{89} - y_{91}), \quad (339)$$

$$\alpha_2'' = a_2' + b_2' = (y_2 + y_{58} + y_{62} + y_{118}) + (-y_{28} - y_{32} - y_{88} - y_{92}), \quad (340)$$

. . . . . .

$$\alpha_{14}'' = a_{14}' + b_{14}' = (y_{14} + y_{46} + y_{74} + y_{106}) + (-y_{16} - y_{44} - y_{76} - y_{104}), \quad (352)$$

$$\alpha_{15}'' = a_{15}' + 0 = (y_{15} + y_{45} + y_{75} + y_{105}). \quad (353)$$

(α')

$$\alpha_1' = a_1 - k_1, \quad (354)$$

$$\alpha_2' = a_2 - k_2, \quad (355)$$

. . . . . .

$$\alpha_{14}' = a_{14} - k_{14}, \quad (367)$$

$$\alpha_{15}' = a_{15} - 0, \quad (368)$$

(α''')

$$\alpha_1''' = a_1' - b_1', \quad (369)$$

$$\alpha_2''' = a_2' - b_2', \quad (370)$$

. . . . . .

$$\alpha_{14}''' = a_{14}' - b_{14}', \quad (382)$$

$$\alpha_{15}''' = a_{15}' - 0, \quad (383)$$

and with the fifteen sine components of the machine set at the respective values (β), (β'), (β'') and (β''')

(β)

$$\beta_1 = b_1 + j_1 = (y_{29} - y_{31} - y_{89} + y_{91}) + (y_1 + y_{59} - y_{61} - y_{119}), \quad (354)$$

$$\beta_2 = b_2 + j_2 = (y_{28} - y_{32} - y_{88} + y_{92}) + (y_2 + y_{58} - y_{62} - y_{118}), \quad (355)$$

. . . . . .

$$\beta_{14} = b_{14} + j_{14} = (y_{16} - y_{44} - y_{76} + y_{104}) + (y_{14} + y_{46} - y_{74} - y_{106}), \quad (397)$$

$$\beta_{15} = 0 + j_{15} = (y_{15} + y_{45} - y_{75} - y_{105}). \quad (398)$$

(β'')

$$\beta_1'' = j_1' + k_1' = (y_1 - y_{59} + y_{61} - y_{119}) + (y_{29} - y_{31} + y_{89} - y_{91}), \quad (399)$$

$$\beta_2'' = j_2' + k_2' = (y_2 - y_{58} + y_{62} - y_{118}) + (y_{28} - y_{32} + y_{88} - y_{92}), \quad (400)$$

. . . . . .

$$\beta_{14}'' = j_{14}' + k_{14}' = (y_{16} - y_{46} + y_{74} - y_{106}) + (y_{16} - y_{44} + y_{76} - y_{104}), \quad (412)$$

$$\beta_{15}'' = j_{15}' + 0 = (y_{15} - y_{45} + y_{75} - y_{105}). \quad (413)$$

(β')

$$\beta_1' = -b_1 + j_1, \quad (414)$$

$$\beta_2' = -b_2 + j_2, \quad (415)$$

. . . . . .

$$\beta_{14}' = -b_{14} + j_{14}, \quad (427)$$

$$\beta_{15}' = -0 + j_{15}. \quad (428)$$

(β''')

$$\beta_1''' = j_1' - k_1', \quad (429)$$

$$\beta_2''' = j_2' - k_2', \quad (430)$$

. . . . . .

$$\beta_{14}''' = j_{14}' - k_{14}', \quad (442)$$

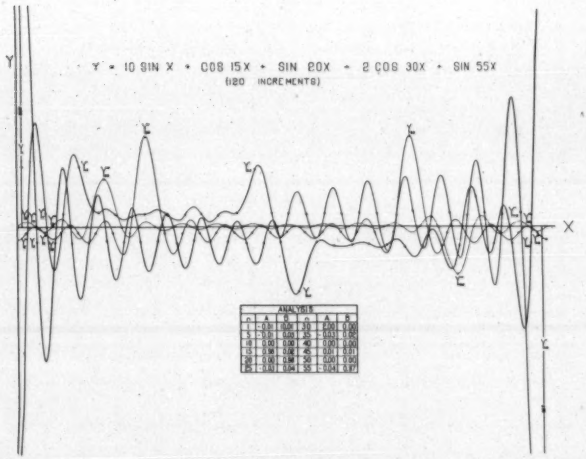
$$\beta_{15}''' = j_{15}' - 0. \quad (443)$$

Figure 9 shows the analysis of a curve represented by a specific equation for fifty-nine harmonics (increments of 3°). The complete traces of the four auxiliary curves are shown in this figure but, of course, the analysis only requires that the

values of specified ordinates from each curve be recorded (read from fixed scale on the machine), and no curves really need to be traced.

The computations for the amplitude settings of the machine can be greatly facilitated by the proper schedule in tabulated values of the ordinates y_n of the curve being analyzed, and the computations of the harmonic components,

FIG. 9.



Analysis (increments of 3°).

A_n and B_n, are facilitated by the proper schedule in tabulated values of the ordinates Y_n, Y_n', etc. from the auxiliary curves.

In addition to the usual applications of synthesizers and analyzers, this machine has been used for the interpretation of harmonic solutions of differential equations and it has been used to synthesize crystal structure data to determine interatomic distances by the Patterson [7] method. Some specific applications of the machines as an analyzer are: hidden

[7] A. L. Patterson, *Phys. Rev.*, **46**, 372–376.

periodicities in strata of cores from oil wells or in weather conditions, etc., and analyses of cardiograms and of wave forms of tones from organ pipes as influenced by the construction of the pipes.

The author is indebted to the mechanicians, Mr. L. H. Gruber and Mr. Robert Brandt, for the mechanical perfection which they achieved in the construction of this machine, and to Dr. Lucien LaCoste for his valuable suggestions.

PROGRESS OF THE BIOCHEMICAL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.*

BY

DR. ELLICE McDONALD,

Director.

This is the fourth annual report of progress of the Foundation and it may be of interest at this time to recapitulate the postulates to which the organization was committed at its inception. The aims of the Foundation are

(1) The study of disease from a chemical point of view.
(2) The study of new compounds for their therapeutic and beneficent effects.
(3) The study of age and the diseases of age.

We have tried to follow out these aims and have made some progress. In the reports of particular projects which follow the connection between the apparently disconnected problem and its application to disease may not seem obvious. However, it is often better to attack such problems from their fundamental basis in order to get practical information as to the mechanism of the disease and of the effects of curative substances.

Two examples of this may be seen in the first two projects of the chemistry department. Pancreatic hormones and their isolation may seem to have little to do with the aging process, but substances which reduce blood pressure, an age manifestation, have a great deal to do with it. Growth-regulating substances, the second project noted, may seem a general term, yet the hope for cancer is in a treatment which will inhibit growth.

So for the other projects noted in this report, they are direct attacks upon the fundamental mechanism of processes having to do with life and disease.

This has been our effort and the progress during the past

* Presented at the Stated Meeting held Wednesday, November 15, 1939.

year has been more satisfactory than any heretofore. This is in part due to the eagerness and skill of the workers and, in part, to the character of the organization.

It has been the aim in this Foundation to set up a biochemical unit which, by bringing together workers and groups of workers, would make a more or less ideal set-up and overcome the disadvantages of the lone worker. We have brought together chemists, physicists and cytologists and oriented their minds to the consideration of these problems in terms of the unit of life, which is the cell. The physicist thinks in terms of the atom, the chemist in terms of the molecule, but our experiments and their consideration must be considered in terms of the cell.

We have set up certain definite aids to their work. For example, the microchemical department, although doing research on its own, is available for the many analyses of minute amounts of new substances produced in the laboratory. The same is true of the physico-chemical department with its set-up of Beams air-driven centrifuges, Svedberg oil-driven centrifuge and Tiselius electrophoretic apparatus all for the extraction, measurement and identification of small fractions of biological material which may produce effects on the human economy.

A typical example would be the production of a biological fraction, from an organ or a tumor or bacteria, which gives promise of being of some use against disease. This is passed to the physico-chemical department for fractionation to obtain greater purity and for gross identification as to the probable composition. The fractions are again passed back to the cytological department for study as to their effects. The more promising of these fractions are in turn passed to the micro-chemists for analysis, possible identification and, if identification is incomplete, for an opinion as to the possible composition. When the active fraction is obtained, it is then studied with a view to its production in pure crystalline form. In this, the organic chemists are called upon, and the last phase, after a pure crystalline product is obtained, is to produce a synthetic substance similar in character and effects to the active product.

The whole gamut is thus run through and, although this is a typical study, many of which are always in progress in the laboratory, each one necessitates certain deviations as to procedure often involving spectrographic, optical, radiological, immunological, manometric or other studies.

Such studies require coördinated effort with mutual consideration and good will among the workers. With such organization results may be obtained which are impossible in limited and uncoördinated groups. It is an effort toward an ideal in the study of disease from a biochemical point of view and while it will probably always fall short of the ideal it is a great advance in biochemical and biological study in relation to human ailments.

CHEMISTRY DEPARTMENT.

The chemistry research staff consisted of ten members during the past year. Experimental work was carried out in the general areas indicated in former reports, including tissue fractionation for physiologically active principles, enzyme activities in normal and diseased tissue, biochemistry of glutathione and other sulfur compounds, bacterial metabolism, carbohydrate metabolism of tissues, and synthesis of organic medicinals. In addition, several new projects were initiated, among which the most important were studies on the mechanism of sulfanilamide action, and on the stereochemistry of the amino acids present in cancer tissue. This report briefly describes the various lines of research in progress.

Pancreatic Hormones.—Our efforts in the field of tissue fractionation have been considerably extended in the past year. One of our aims is the elucidation of the active principles—hormones—contained in pancreatic tissue. Insulin is the most important of these thus far discovered, and its properties are well known. Our interest is chiefly in isolating the substances, in pure form, which are responsible for the following effects produced by pancreas extracts:

(*a*) Reduction of blood pressure—adrenalin neutralizing fraction.
(*b*) Heart block (arrhythmia) and subsequent death.
(*c*) Regulation of fat metabolism or fat mobility.

Some evidence has been obtained that the substance which produces heart block is sphingosine choline phosphate, a precursor or a hydrolysis product of the phospholipid, sphingomyelin. A crystalline substance has also been isolated from pancreas which causes a marked *reduction* of liver fat in normal male mice, but an *increase* in females. Interestingly enough this same compound has a profound effect on blood pressure, producing a hypotension of long duration in both normal and anesthetized rabbits. The substance in doses as low as 0.3 milligram per kilogram body weight causes a 50 per cent drop in blood pressure, lasting for hours and returning slowly to normal over a period of several days. It seems that these two widely divergent effects may be secondary results of a primary effect on the autonomic nervous system. The substance appears to be a purine base but has not been identified. Considerable work is in progress on the relation of this material to fat metabolism in the body. A study is also being made of faulty fat metabolism as a possible causative factor in anemia.

Growth-Regulating Principles in Tissues.—Another project in the field of tissue fractionation has for its aim the isolation of substances which stimulate or retard growth. Some tissues, such as embryo and tumor, grow rapidly; normal adult tissue, apparently, has ceased growing. It has frequently been suggested that every tissue contains both growth-promoting and growth-retarding principles, and that the relative amounts of these two classes of substances present determine the state of growth of a particular tissue.

An effort is being made to separate, from normal adult tissues which have apparently ceased growing, a substance which will exert an inhibitory effect on cancer growth. Thus far only thymus tissue has been extensively fractionated. Extracts prepared in various ways are generally tested first for their effect on the growth of corn roots. It has been found possible to obtain preparations which are very strong inhibitors of corn root growth. When rats bearing transplantable tumors are injected with the same extracts, the growth of the tumors is not greatly influenced, although the rats as a whole do not grow as rapidly as do untreated controls. Inhibitory effects on tumor growth have, however,

been obtained in the case of spontaneous mouse tumors. Because of its importance to the cancer problem, the work is being extended to the fractionation of other tissues besides thymus.

Blood Phosphatase.—In the previous report a method was described for the study of blood enzymes, using the Linderstrøm-Lang micro-technique. In principle, the method consists in the removal, at stated intervals, of a drop of blood from the tail of a rat having cancer or some other disease or condition under study. The drop of blood is then analyzed for enzyme activity by means of the micro-technique. The method is advantageous because of the small amounts of blood required; changes in enzyme activity can be followed on individual rats throughout the entire course of a given disease or experimental period. Thus it has been found that the blood proteinase level drops considerably during the course of cancer growth, and also during pregnancy. But if the cancer is removed by operation, or if the pregnancy terminates, the proteinase level returns to normal.

During the past year similar work has been carried out on blood phosphatase, an enzyme intimately concerned with the metabolism of sugars and fats, and with the process of bone formation. It was found that when rats are starved for 24 hours, their blood phosphatase drops nearly to zero, but if feeding is resumed, the enzyme level is restored to normal within a few hours. This interesting phenomenon has been studied in considerable detail. It is probable that some particular factor, associated with the *fat* fraction of the food, is responsible for the regulation of the phosphatase level in the blood. Its exact nature is, however, not yet known, although it appears to be lipoidal. Extensive experiments are in progress to obtain further knowledge on this relation between blood phosphatase, fat metabolism, and the fat-regulating principle found in pancreas.

Synthesis of Organic Medicinals.—A group of three research chemists devoted the entire year to the synthesis of new organic compounds of possible therapeutic value. The main line of work was carried out in the field of sulfanilamide and sulfapyridine analogs. The discovery of the remarkable chemotherapeutic properties of this type of drug in a wide

variety of infectious diseases constitutes one of the really brilliant chapters in modern medical research.

During the past year about 25 new compounds have been made by our group. They were, in general, similar in structure to sulfanilamide, but contained pyridine, quinoline, or acridone groupings in place of, or in addition to, the benzene nucleus present in the former. It was expected that these additional groupings, which in certain combinations possess valuable medicinal properties themselves, might augment the therapeutic effects of sulfanilamide. A number of analogous compounds, containing pyrimidine, guanidine, urea, and other amino compounds, have also been made. Pharmacological tests have shown that a number of the compounds made possess some protective action against hemolytic streptococcus. However, none thus far tested is equal to sulfanilamide in this respect.

Mechanism of Sulfanilamide Action.—Attempts to find or make therapeutic agents more powerful than sulfanilamide have thus far been conducted on a "trial and error" basis. Since very little is known of the way in which this drug exerts its remarkable effect, it cannot be predicted in advance what type of compound is likely to be of greater value. For this reason our emphasis has been diverted, somewhat, from the purely synthetic side, and placed more upon the question of the mechanism by which these drugs act. Once this is thoroughly understood, it will be much simpler to decide in which direction the synthetic work ought to go.

During the past year considerable evidence has accumulated to show that when sulfanilamide is given to an infected subject, it acts directly on the invading pathogenic organisms, and not indirectly by stimulating the normal bodily defense mechanisms. It appears to stop growth of the organisms by inhibiting one or more of their vital metabolic processes. According to some investigators it exerts its effect by inhibiting certain enzyme systems, such as proteinase, catalase, or dehydrogenases.

Our laboratory has initiated a study of the effect of sulfamilamide and related compounds on various enzyme systems found in animal tissue and in pathogenic and nonpathogenic bacteria. Towards many enzymes these com-

pounds are quite inert; towards others, such as certain dehydrogenases, and in particular, catalase, the hydrogen peroxide decomposing enzyme, marked inhibitory effects are shown.

Of especial interest is the finding of Mellon, confirmed in our laboratory, that sulfanilamide previously irradiated with ultraviolet light is very much more effective against catalase than is the unirradiated compound. The sensitivity of dilute solutions of the drug toward ultraviolet light is quite remarkable. A blue color is formed, probably by oxidation.

In view of this easy oxidizability under proper conditions, it is possible that, in the body, sulfanilamide is oxidized to some intermediate product, which then acts as the true therapeutic agent. Attempts are now in progress in our laboratory to synthesize some of these intermediate products, so that the theory outlined can be thoroughly tested.

Metabolism of Staphylococcus aureus.—It is conceivable that chemotherapeutic effects in general may come about by an inhibition in the chemical reactions from which the growth energy of the pathogenic organism is obtained. For this reason it is of value to determine the mechanism whereby an organism obtains its energy. This is being done by studying the bacterial metabolism of carbohydrates and amino acids by means of a combination of manometric and analytical techniques.

In this work, the steps by which carbohydrates or amino acids are oxidized or converted into their final products are being established. When the various stages in these biological oxidation processes are clearly understood it will be possible to study the action of sulfanilamide, or of any other physiologically active substance, for its effect on each individual reaction concerned. This should lead to valuable information on the mode of action of various drugs.

Work to date has been confined to the facultative anaerobe, *Staphylococcus aureus*. In their anaerobic metabolism the *Staphylococci* resemble the great group of *Streptococci* to which they are quite similar morphologically. The general procedures evolved in this work will later also be extended to the study of certain pathogenic bacteria which are affected by sulfanilamide.

Manometric Method for Pharmacological Testing.—The determination of bactericidal efficiency of a disinfectant usually consists in finding the most dilute concentration of the substance in question which will sterilize a suspension of bacteria in a definite time under definite experimental conditions. During the past year, a new method has been developed which is more rapid and of higher accuracy than the older method. It consists in measuring, by means of Warburg manometers, the percentage inhibition of respiration produced by the substance under study when brought in contact with a suspension of respiring bacteria under standard conditions.

It was found that, under proper conditions, the oxygen uptake of bacterial suspensions (*Staphylococcus aureus, Proteus vulgaris, Pseudomonas fluorescens*) is directly proportional to the growth of the bacteria. Consequently, by measuring the effect which a given substance has on the respiration of such a suspension, one obtains a measure of its effect (i.e., bactericidal or bacteriostatic) on growth. Numerous compounds have been tested by this procedure and it was found that those which inhibit respiration also inhibit growth by the same percentage.

Of interest is the observation that sulfanilamide inhibits bacterial respiration, but only in concentrations much higher than those normally used in clinical treatment. The explanation may be that the drug is converted into a more powerful bactericide in the animal body.

The method just described has thus far been used only in the study of bactericidal action. Efforts will be made to extend its usefulness to other fields of pharmacological testing.

Carbohydrate Metabolism of Tissues.—Considerable emphasis has, in former years, been placed upon the question of the nature of carbohydrate metabolism, particularly on oxidation mechanisms. No work was done in this field in the past year. However, certain phases have again assumed considerable importance, and plans have been made for continuing the research in two directions.

One of these involves the enzymes, succinic and malic dehydrogenases. These are key enzymes in normal metabolism, but apparently they are missing (or inhibited) in

cancer tissue. The result is that cancer exhibits an abnormal type of metabolism. It is proposed to determine the reason for the inactivity of these enzymes in cancer tissue. If an inhibitor is present, it would have an important bearing on the cancer problem.

The second question involves the study, by manometric methods, of the effect of insulin on carbohydrate metabolism of tissues. It includes a study of metabolism in insulin and metrazole shock. Such work is of interest both in the study of diabetes and of mental disease (shock treatment).

The Glutamic Acid of Cancer Tissue.—Several months ago, Kögl and Erxleben, working in Holland, reported a most remarkable chemical difference between cancer and normal tissue proteins. As was well known previously, proteins can be broken down by acid hydrolysis into the various constituent amino acids. When the amino acid, glutamic acid, is isolated from any natural protein, it always has the property of rotating a plane of polarized light to the *right*. When pure, this so-called natural $l(+)$ form has a specific rotation of about $+31.0$ degrees as measured in a polarimeter. Kögl and Erxleben now found that the glutamic acid of tumor proteins contains considerable amounts (15 to 44 per cent.) of an abnormal form of glutamic acid, namely the $d(-)$ form, which always rotates plane polarized light to the *left*. When pure, this abnormal form has a specific rotation of -31.0 degrees. Kögl found that other amino acids in tumor protein also show this same stereochemical abnormality, but not to the extent exhibited by glutamic acid.

These findings of Kögl have been confirmed and extended by us. The problem is made complicated by the fact that the sought-for abnormal $d(-)$ form of the acid is much more soluble than is the normal form, so that it tends to stay in solution. The problem is of such importance that various other groups of workers have been attracted to it also. Some of these have claimed confirmation, others found no evidence to support Kögl's findings. Now that the findings can be substantiated it will mean an important advance in cancer has been made. It will probably mean that an improperly adjusted enzyme system in the cancer cell, or in the potential cancer cell, is causing a rearrangement of the glu-

tamic acid to the abnormal form. This would require an investigation of those enzymes concerned in amino acid metabolism.

Biochemistry of Sulfur.—Most of the work in this field has been concerned, as usual, with the question of the role of the naturally occurring sulfur compound, glutathione, in vital processes. Refinements have been added to the new specific methods, described in the previous report, for the estimation of glutathione. These methods, which should prove to be of considerable value in this field, depend upon the reduction of oxidized glutathione by electrolysis, and the subsequent determination of the reduced glutathione by means of its specific activating effect on the enzyme glyoxalase. Publications have also appeared which describe our improved method for isolating glutathione from yeast, as well as the isolation of radioactive glutathione from yeast grown on a medium in which radioactive sulfate was the only source of sulfur.

Considerable attention was also given to the enzyme system (antiglyoxalase) of kidney and pancreas which hydrolyzes glutathione into its constituent amino acids. This enzyme system, or one closely related to it, has been shown to occur also in blood. The claim was first made (Waldschmidt-Leitz) that the enzyme was present only in the blood of cancer patients, and not in that of normal subjects. In an effort to determine whether this observation might be made the basis for a cancer diagnostic test, extensive studies were carried out on various human bloods. It was found that the enzyme in question occurs in normal as well as in pathological bloods. The range of concentrations covered is approximately the same in both types.

CYTOLOGY DEPARTMENT.

Bacteriological Investigations.—A very thorough and exhaustive study has been made of the factors influencing capsule formation by Friedländer's bacterium. It has been found possible by the proper control of the cultural conditions to produce organisms either with very large capsules or with no capsules at all. Pathogenicity apparently is closely related to capsule formation in many organisms. This group of

bacteria is pathogenic when they form capsules, but non-pathogenic when they do not form capsules. It was found possible to change a pathogenic, capsule-forming strain into a non-pathogenic strain incapable of forming capsules by altering the cultural conditions.

The polysaccharides present in these capsules have been studied. There were found two polysaccharides, one containing nitrogen, the other nitrogen-free. The polysaccharide which contained nitrogen was much more active serologically.

The use of the manometric method for the evaluation of germicides was investigated. It was concluded that further studies are advisable before this method can replace the older methods.

Forty new chemical compounds were tested for their effects on streptococcus infections in mice. Only two of these compounds were found to affect the course of the infection, and neither of them was as active as sulfanilamide.

A study has been made of the rapidity of passage of bacteria from the peritoneal cavity into the blood stream of rats. The rapidity of passage varies greatly with the species of bacteria and is not correlated with the size of the bacteria. Experiments indicate that a parallelism exists between the iso-electric point of the bacteria and the rapidity with which they pass into the blood stream. Evidence from another source seems to support this hypothesis. When injected intraperitoneally, these bacteria affect the differential blood counts, as shown by an increase in the relative number of polymorphonuclear leucocytes and a decrease in the relative number of lymphocytes. The lower the iso-electric point of the bacteria injected, the longer does this effect persist. The same effect is produced by edestin, and casein. Here again, the lower the iso-electric point of the protein injected, the longer the effect on the differential count exists. Thus, it appears that this response of the body to the injection of bacteria is due to the fact that foreign protein is introduced, rather than to the fact that bacteria, *per se*, are injected.

Virus work.—A filterable agent, believed to be a virus, which caused pyogenic abscesses in rats was investigated. Studies were made of its resistance to chemical agents, and it was concentrated by means of ammonium sulfate precipita-

tion and the use of the ultracentrifuge. The results were not uniformly successful.

After a time it was decided that possibly the agent was a filterable bacterium rather than a virus, and since other workers had reported the culture of a pleuro-pneumonia like organism from the lesions, efforts were made to cultivate the agent on artificial media. These efforts were successful. The assumption has been made, therefore, that the agent is a bacterial organism, rather than a virus, as was at first supposed.

Studies on Allergy.—Human allergic serum was fractionated in the Tiselius electrophoresis apparatus and the fractions tested for the skin sensitizing antibody in order to determine whether the antibodies appeared in the same fractions as did other (bacterial) antibodies. No difference was found. This had previously been a disputed question, and assumptions had been made that a difference existed.

It has been uncertain in allergy as to whether or not a true union occurs between the allergen and its antibody. Evidence was obtained by two methods indicating that such a union does not occur: (1) A mixture of human allergic serum and its antigen was subjected to ultracentrifugation. Samples from the top, middle and bottom of the centrifuge tube were tested for antibody to staphylococcus toxin in a control serum, and for the allergic antigen in the other case. There was a distinct downward movement of staphylococcus toxin antibody while the allergic antigen was not appreciably sedimented. This apparently means that there was no union between the allergen and its antibody, or else the speed was insufficient to sediment so small a body. (2) Measurements were made of the scale deviation caused in the Tiselius electrophoresis apparatus by human allergic serum and its allergen. No difference was found between the globulin fractions alone and in the presence of allergen. This is considered to be negative evidence in respect to a union between antibody and allergen in human allergy.

Effects of X-rays on Jensen Rat Sarcoma.—A careful study of the effect, as shown by growth and histological structure, of therapeutic doses of X-rays on Jensen Rat Sarcoma was made. Subcutaneous tumors were given measured doses of

X-rays. The growth of the tumors was then followed by measurements. At 24 hour intervals tumors were removed and histological examinations made in order to observe the effects of the radiation. These experiments were designed to serve as a basis for a comparative study of the effects of X-rays and neutrons, in therapeutic doses, on transplantable animal tumors.

MICROCHEMICAL DEPARTMENT.

The scope of work in the microchemical department has been widened considerably. The routine analyses on samples supplied by the various research groups of the Foundation still occupied most of the time and energy of the analysts, but it seems that due to improvements in the methods and better distribution of the work more time became available for definite research problems. "Trouble shooting," as it was successfully coined in another microchemical laboratory, still remains one of the major tasks of the microanalyst. Quick solutions of problems or indications of "true or false" are important not only for the research worker, who otherwise would be delayed in the continuation of his problem or brought onto a false path, but also for the analyst. The latter can save considerable energy, valuable materials and reagents, and, above all, time. Many of the tricks developed for the solution of a special problem prove to be so valuable for general purposes that they are followed up as time permits and published later for the benefit of the analytical profession.

Biochemical Methods and Their Value in the Diagnosis of Disease.—It is of considerable importance to know whether or not biochemical methods can be used to differentiate various types of one disease and thus help the medical profession in making a more detailed diagnosis. As a coöperative problem in this direction, complete blood analyses have been carried out on samples obtained from cases with atheromatous cardiovascular disease, arteriosclerosis, and coronary thrombosis.

The analytical part of the problem was treated very carefully to eliminate any personal errors, the analyst being supplied with unknown duplicate and triplicate samples of original blood or after the addition of known amounts of the

constituent being analyzed. Certain improvements in the procedures have been incorporated as experience was accumulated, so that the precision and accuracy of each method was established satisfactorily. Statistical methods have been applied in the evaluation of over 2000 single determinations of the following constituents:

Potassium-Calcium ratio in serum: potassium by the Kramer and Tisdall method, calcium by the Kramer and Tisdall method in the modification by Clark and Collip;
Total phospholipids in 1 ml. blood: extraction by Bloor's method, oxidation to phosphate and colorimetric estimation according to E. J. King;
Blood sugar in 0.1 ml. blood: Hagedorn and Jensen method;
Cholesterol in serum according to Schoenheimer and Sperry, giving directly the total cholesterol and free cholesterol, and the esters being calculated as the difference.

The evaluation of the results indicated that no definite change of the constituents from the values established for normal conditions was noticeable; in this special case it seems of little value to use these methods for diagnostic purposes.

The evaluation of the results from the clinical viewpoint, as distinguished from the above analytical viewpoint, will be carried out elsewhere.

Application of the Linderstrøm-Lang Microtechnique.—Work in fields similar to the above should be facilitated considerably by including animal experiments. The known difficulties, upsetting the conditions of an animal by taking blood samples large enough for complete analyses, can be overcome by taking about 1/20 of the amounts previously necessary. The use of highly sensitive microprocedures becomes evident, and as a first step the microtitration procedures of Linderstrøm-Lang and Holter were applied to the determination of calcium in serum. In general, the procedures by Siwe, and the one by Sobel and Sobel were followed, but these are only the initial stages of the problem. Previous experience was centered around cholesterol determination, as it has been reported.

Radioactive Substances.—The synthesis of organic compounds containing radioactive sulfur atoms (S^{35}) was con-

sidered to be of importance for future work. The strictly biological synthesis (in vivo) of glutathione* [1] carried out in this Foundation was to be supplemented by a chemical synthesis (in vitro) of organic sulfur*-compounds, which, because of knowledge concerning other artificial radioactive elements, offered no special difficulties. Because only a small amount of S^{35} with a comparatively low activity was available, the application of microtechniques for the synthesis and of micromethods for the analysis were essential.

Two intermediate products in the synthesis of sulfanilamide* were prepared, 4,4′-dinitrodiphenyl disulfide* and p-nitrobenzenesulfonyl chloride*. Their identity and purity were confirmed by microanalysis. The results of the radioactivity measurements in special Geiger counters were compared with those obtained from purified sulfur* samples and the expected ratios obtained. This is considered to be another preliminary step towards the general application of radioactive sulfur atoms in the search for elucidating the fate of compounds in the body.

Microanalytical Procedures.—The application of the systematic scheme of *qualitative organic microanalysis* has given highly satisfactory results, and more experience was obtained. In addition to previously mentioned procedures a new microrefractometer was developed for the measurements of the refractive index of liquid samples in the amount from 6 to 8 cu. mm. Based on the principle of L. Nichols, the capacity of the cells, which are formed by two glass prisms mounted into a metal ring, is reduced to 1/20 of the macro instrument. The special advantage of the microrefractometer is found in the recovery of about 80 per cent. of the unchanged material. The range of refractive indices extends from that of water to 2.00 by using two cells with prisms of refractive index 1.25, and 1.75, respectively. The accuracy is well within ± 0.001 and can be increased to within ±0.0005 if light and temperature conditions are controlled by colored filters and a water jacket around the cell.

The microrefractometer is mounted in a glass slide and the distance between two lines, which are produced by the differ-

[1] Elements and compounds containing radioactive atoms are identified with an asterisk, such as glutathione*, sulfur*, etc.

ence in the refractive indices of the liquid and glass prisms, is measured with an ocular micrometer of a microscope. The efficiency of this instrument has been tested in comparison with an Abbe refractometer, using a series of organic liquids with highly different physical constants.

In another phase of the work on the qualitative scheme micro extractors of varying design have been used for the extraction of the active ingredients of some common drugs, such as asafoetida with alcohol, aloe with water, and lupulin with ether. This investigation showed that by employing micro extraction apparatus results comparable with that of the conventional Soxhlet extractor were obtained, but less sample was needed with a consequent saving in time. Slight deviations in the results from that of the standard apparatus seem to be constant with the particular microapparatus.

Mixing and pulverizing or grinding centigrams or milligrams of an organic compound are operations which are frequently required in microanalysis. The ordinary small agate mortars are unsatisfactory for this purpose because of their construction. Incomplete mixing and high losses of material are observed; the latter especially must be prevented if the advantages of the qualitative scheme or microanalysis in general are not to be diminished. A micromortar of porcelain was developed for the small amounts under consideration and tests showed its efficiency for soft and medium hard materials, such as are dealt with in organic synthesis and analysis. Important features of the new design are the ratio between the inner curvature of the mortar and the outer curvature of the lower part of the pestle, and a wider base for better support.

The studies on the determination of selenium in organic compounds by means of gravimetric micromethods have been continued. Since a few pure selenium compounds became available, the accuracy of the method could be ascertained to be within $\pm$ 0.3 per cent. The new method consists in the combination of the best features of two known methods, by Wrede and by Drew and Porter, with some minor improvements. It is of considerable advantage that this method is generally applicable, no interference being noticed in the presence of N, S, halogens, and As. Recently the results of

this work appeared in the Notes from the Biochemical Research Foundation, in the Journal of the Franklin Institute.

The nitrogen determination by the micro-Dumas method has been frequently investigated and improvements announced. To keep up with the newest developments our investigations centered around all important parts of the set-up, such as the source of carbon dioxide, using different types of generators filled with dry-ice, the regulation of the speed of gas flow by means of newly designed needle valves instead of the stopcock, and the nitrometer, especially supporting the importance of accurate dimensions to within 0.1 mm. in some of the parts.

PHYSICO-CHEMICAL DEPARTMENT.

Purification of Therapeutic Antiserum.—The progress report of last year mentioned that a technique had been devised by which it was possible to concentrate and purify therapeutic antibodies with the aid of the ultracentrifuge. This method of purification was dependent upon the addition, in relatively small amounts, of a specific aggregating agent to the antiserum. The aggregating agent was an antigen specific for the antibody in the immune serum. Under specialized conditions one was able to add a relatively small amount of diphtheria toxin to the antitoxic serum, and ultracentrifuge at 100,000 × gravity for two or three hours. Ultracentrifugation yielded a sediment fraction which contained substantially all of the antitoxin, approximately 3/4 of which was capable of neutralizing toxin. Presumably, the other 1/4 was already neutralized by the toxin added for the purpose of specific aggregation. Because of the high cost of producing the antigen to act as the aggregating agent, the method was considered economically impractical.

In order to simplify the procedure, less specific methods for aggregating the antibody component were examined. It was found that if anti-pneumococcus horse serum was heated to 60° C. for 15 min. and subsequently ultracentrifuged, a considerable purification of antibody component was effected. This concentration of antibody component was measured by *in vitro* titration in terms of combining equivalent and protein nitrogen precipitable by specific carbohydrate. *In vivo* titra-

tion in terms of mouse protection units indicated that the aggregation of antibody which resulted from heat treatment caused a considerable diminution in protective activity of the purified component. Therefore it is considered necessary, if the antibody component is aggregated for purpose of ultracentrifuge fractionation, to redisperse the antibody protein or suffer loss in protective activity.

Electrophoretic Analysis of Heated Antiserum.—Electrophoretic studies in the Tiselius apparatus have made it possible to observe quantitatively the changes produced in antipneumococcus horse serum (Type II) by mild heat treatment (64°–65° C. for 10 min.) and subsequent ultracentrifugation. Electrophoresis causes the separation of electrochemically dissimilar protein constituents of a mixture and gives, so to speak, an electrophoretic spectrum of the solution. Normal serum, for example, exhibits four protein components, albumin, and alpha, beta, and gamma globulin. Special optical methods of observation based on the extent to which a beam of light is refracted in different parts of the solution, make it possible to determine as well the concentration of each component.

The Type II antipneumococcus horse serum, which was used for these experiments, gives an electrophoretic diagram similar to that of normal horse serum except for an unusually high content of gamma globulin. Diagrams obtained before and after removal of the antibody by means of the homologous polysaccharide show that the antibody activity is associated with the gamma globulin and accounts for its high concentration. However, the point deserves mention because in Type I antipneumococcus horse serum, which it might be expected to resemble, the antibody migrates as a separate constituent between beta and gamma.

After heat treatment at 64°–65° C. for 10 minutes, Type II antipneumococcus horse serum shows a moderate increase of beta at the expense of gamma. Ultracentrifugation of the heated serum causes removal of about one-half of the remaining gamma, together with small amounts of the other constituents. Parallel immunological tests demonstrate that the antibody is completely removed from the supernatant fluid and concentrated as a gelatinous sediment.

However, the electrophoretic diagram of the sediment fraction resuspended in buffer solution shows not a preponderance of gamma with small amounts of albumin, alpha, and beta, but a preponderance of beta with small amounts of albumin, alpha and gamma. Diagrams of the sediment fraction both before and after the removal of the antibody by precipitation with homologous polysaccharide, demonstrate that the antibody activity, i.e. specifically precipitable protein, is now associated with the beta globulin. All but a small fraction of the beta component is specifically precipitable with the polysaccharide. One is forced to the conclusion that during the process of aggregation and resuspension the antibody has undergone a shift in mobility. The mechanism of this change has not yet been determined.

Electrophoretic Analysis of Allergic Serum.—Electrophoretic studies also have been conducted on normal and allergic human sera. No substantial electrochemical distinction could be found between the two. Passive transfer tests on allergic sera fractionated by means of electrophoresis indicates that the skin sensitizing antibody was confined to the gamma globulin component. The antibody for ragweed in rabbits was found to be associated with the same fraction. Parallel electrophoretic fractionations of the antitoxin against staphylococcus hemolysin was also found only in the gamma globulin.

The electrophoretic diagrams of human sera exhibit considerable variability when compared with horse serum, for instance. While these variations are difficult to correlate with physiological changes, further study is extremely promising.

Ultracentrifuge Development, Rotor Steel.—Since efforts are constantly being expended toward increasing the efficiency of fractionation in the ultracentrifuge, and since the continuous separation ultracentrifuge is most satisfactory for the handling of large volumes of fluid, data concerning the maximum safe rotational speeds of ultracentrifuge rotors is extremely important. The choices of steel for rotor material is not the simple matter of obtaining steel of the highest possible tensile strength because steels of extremely high tensile strength are also very brittle. A rotor made of a brittle steel readily becomes fatigued, or in other words, it is apt to explode under

moderate rotational stresses. To assure dependable operation over long periods the steel from which the ultracentrifuge rotor is made must be as resistant to fatigue as possible.

Fatigue characteristics such as will permit operation over long periods under repeated stresses are found in the more elastic but lower tensile strength steels. Therefore a problem in ultracentrifuge development is the choice of optimal characteristics of tensile strength and elastic limit from available steel alloys. A series of eight steel rotors are being tested in triplicate in this laboratory for suitability as rotor steel. Tests necessitate the explosion under centrifugal force of an ultracentrifuge rotor made from each steel to determine the rotational speed at which failure occurs. Since we are at present in the midst of these tests results concerning the choice of rotor steel must be deferred.

Ultracentrifuge Development, Rotor Geometry.—The continuous separation type of ultracentrifuge possesses a rotor which is in the form of a thick walled tube, capped on the ends, and which spins on the axis of rotation of the tube. This form of rotor lends itself quite satisfactorily to stress analysis. When a thick walled tube of this type fails due to excessive centrifugal stress, failure first occurs at the inner surface of the tube. This is because the tube under stress tends to expand as a whole; since the inner surface is shorter in peripheral length than the outer, the inner surface must fail first. The more nearly the inner diameter of the tube approximates the outer, the more resistant to failure will the tube be under centrifugal force, that is when the tube is empty. As soon as fluid is contained in the rotating tube, wall thickness must be increased to withstand hydrostatic pressure. Therefore, the maximum strength of a tubular rotor of a given steel designed to handle fluids is dependent upon the ratio of wall thickness to tube diameter. It is planned that this statement be investigated as soon as data on the best available steel alloy for rotors are complete.

Ultracentrifuge Analysis of Pneumococcus Polysaccharide.—Pneumococcus polysaccharide prepared according to the method mentioned below was tested in the analytical ultracentrifuge of the du Pont Experimental Station. The polysaccharide exhibited a single well defined boundary in the

ultracentrifuge and appeared to be homogeneous. A series of ultracentrifuge runs on polysaccharide solutions of varying concentration was necessary before the sedimentation constant could be estimated. While a figure for the sedimentation constant has been obtained, the analysis has been carried through on only two specimens of molecularly homogeneous polysaccharide. The value for S_{20} must wait confirmation. Also determination of diffusion constant will be necessary to the definition of molecular weight.

Bacterial Enzymes.—Studies on the proteinase of C. histolyticum (purified by electrophoresis) have indicated that the absorption band attributable to tyrosine, tryptophane, or phenylalanine, was absent from the ultraviolet absorption spectrum. Measurements of electrophoretic mobility and isoelectric point are to be made on a number of such purified preparations.

IMMUNOLOGY DEPARTMENT.

An investigation of certain differences between the pathogenic and non-pathogenic members of the spore-forming anaerobic bacteria revealed that the proteolytic enzymes of the non-pathogenic bacteria were inhibited markedly by normal blood serum, although the enzymes of the pathogenic organisms tested (C. histolyticum, C. welchii, C. oedematiens-maligni) were not inhibited. The enzymes of the pathogenic organisms were inhibited by immune serum, however.

This problem—that of determining the essential differences between pathogenic and non-pathogenic bacteria—will be investigated more fully, especially as regards the destruction of tissue and the formation of toxic compounds in the animal body.

It was desired to study the combination of pneumococcus antibody and its antigen, the polysaccharide of the pneumococcus, with the Tiselius electrophoresis apparatus and the ultracentrifuge. To do this it was necessary that both substances, the antibody and the polysaccharide, be quite pure and homogeneous. Consequently, some time was spent on the preparation of pneumococcus polysaccharide which would be mono-disperse in the ultracentrifuge. This was accomplished by using very young cultures of pneumococci as the

source of polysaccharide and keeping the temperature as low as possible during the preliminary steps of purification, to lessen the effect of the carbohydrate-splitting enzymes of the pneumococci on the polysaccharide.

After purification, the polysaccharide was type specific, contained phosphorus as an integral part of the molecule, yielded solutions of high viscosity, and appeared to be monodisperse in the analytical ultracentrifuge.

In the study of the effects of heat upon antipneumococcus serum it was found that when antiserum was heated gently, the antibody was altered in such a way that an excess of serum no longer precipitated with a small amount of the specific pneumococcus polysaccharide. However, the ability of this heated antibody to combine with the polysaccharide was changed but slightly. Not all antipneumococcus sera were identical with regard to this effect of heat treatment. The disappearance of precipitating ability seemed to be more marked with fresh samples of serum than it was with serum which had been aged for a year or more. Further, with well-aged serum, heating at a higher temperature, or for a longer period of time, restored in part the ability of the antibody to precipitate with the polysaccharide. This effect of heat on antipneumococcus antibody seemed to be correlated with an aggregation of the antibody molecules.

LIBRARY.

Publication.—During the research year September 1938 to September 1939, 20 publications appeared; 12 additional articles were in press at the close of the year. The "Notes from the Biochemical Research Foundation" appeared each month in the JOURNAL OF THE FRANKLIN INSTITUTE, beginning November 1938. These "Notes" contain reviews of the scientific publications which had appeared during the preceding month. They also contain descriptions of work in progress in the laboratory at the time. In addition, they frequently include descriptions of methods, procedures, apparatus, which were considered to be not of sufficient importance to be published in scientific journals but of sufficient value to be placed on record. The "Notes" therefore are a cross-section of the progress of the Laboratory month by month.

In connection with the publications and "Notes" an intramural publications committee was instituted. The members of the Library staff serve on this committee, together with several members from different other departments. Proposed articles and "Notes" are submitted to the committee which renders constructive criticism and supervises the preparation of the typescript, submits it to the Editorial Committee, and prepares the approved copy for press.

When publications have appeared in press, the reprints are added to our laboratory files, which now number 155 publications. Reprints are also prepared for our bound volumes of "Reports of the Biochemical Research Foundation," of which volume V will appear this winter.

Journals.—The journal section of the library was moved into a wing of the Hoffman Library. The stacks have been arranged so as to form reading cubicles. New journals are displayed for one week on the "current shelf"; 105 scientific journals are received periodically by our Library.

Reference Material.—It is the aim of the library to fulfill every demand for reference material on the part of members of the staff. During the past year this aim has been carried out as fully as possible through the various channels open to the Library. The books, journals and reprints have served to supply most of the material required by staff members. In addition, photostat copies of articles have been made in the laboratory and some such copies have been obtained from outside sources.

Reprint Collection.—The reprint collection continues to be one of the most valuable assets to the laboratory. It is more flexible and easier to keep up to date than material in book form, and the small size of the reprints makes them convenient for the use of the workers. A wide range of subjects is covered in the collection, and during the past year papers from several new fields have been included. It is estimated that about 100 reprints a month are read and utilized by staff members. Our reprint collection now numbers 23,238 classified and catalogued articles.

Sensitive.—(*General Electric Review*, Vol. 42, No. 8.) A device so sensitive that it will indicate the differences in thickness of a fingerprint on a piece of smooth glass, has been developed by J. A. SAMS of the G.E. Works Laboratory at Schenectady. Known as a surface indicator, the instrument is used to determine the smoothness of metal or painted surfaces and indicates minute variations far beyond the range of the human eye. Variations of as little as 1/1,000,000 in. are clearly indicated. By its application, the surfaces of bearings or other moving parts of motors and the like that are subject to wear may be tested and their smoothness indicated. The apparatus appears somewhat like a phonograph with its turntable on which is placed the object to be tested, and its sapphire-pointed stylus or needle that passes over the test material as it revolves. Small mechanical impulses are created as the hard point rides over surface irregularities. These impulses are then transmitted to an electromagnetic pickup which converts them into electrical impulses. They are then amplified and transmitted to a recording meter where the surface characteristics are graphically indicated. The stylus or needle is so sensitive that when it is placed on the revolving metal turntable, the invisible vibrations established by a person whistling are shown on the recording meter.

R. H. O.

Oil-Treated Storage Eggs Shown at Poultry Congress.—A new oil treatment that has kept cold-storage eggs for six months in practically as good condition as when they were stored, was featured in the U. S. Government exhibit at the 7th World's Poultry Congress, Cleveland, Ohio, recently. Known as the vacuum-carbon dioxide oil treatment, it is a product of research in the Bureau of Chemistry and Engineering, U. S. Department of Agriculture. Several commercial concerns are now using the treatment. The new treatment is important, the Bureau points out, because it means that in the spring when eggs are plentiful, they can be treated and stored and the quality maintained until fall or winter. Then, when hens are not laying so well, these storage eggs will come on the market about as attractive in quality as fresh eggs. The treatment consists of drawing air out of the eggs by vacuum, dipping the eggs in mineral oil, and forcing the oil into the pores of the shells by releasing the vacuum with carbon dioxide. The removal of the air and the substitution of oil and carbon dioxide helps to slow up the loss of moisture and chemical change within the eggs.

R. H. O.

POLARIZED LIGHT FOR MOTOR VEHICLES.

BY

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The problem of glare from motor-vehicle headlights has been without a satisfactory solution since the very introduction of powerful headlight beams. Beam distribution control, though useful to some extent, is obviously not an ultimate answer to the problem. L. W. Chubb has investigated various selective lighting schemes as solutions of the difficulty, and in 1936 he presented a comprehensive paper on the subject before the Illuminating Engineering Society.[1] J. H. Hunt[2] and numerous others considered the possibility of using polarized light for motor vehicles, but the subject remained a rather academic one until the advent of a polarizing material obtainable in sheets at reasonable cost.

From theoretical considerations, it is evident that at least 50 per cent. of the light is lost upon polarization of a headlight beam. Also, there are reflections at the air-glass surfaces of the polarizer and analyzer, and some of the light is absorbed in the polarizing medium. Finally, a portion of the light that is reflected from objects on the roadway is depolarized, and the analyzer in front of the driver's eyes produces a marked decrease in the brightness of objects.

It must be remembered, however, that if all cars were equipped with polarizers, there would be no need to limit the candlepower of the source as is done at present. Legislative authorities have feared, and to a certain extent rightly so, that increasing the candlepower, with its subsequent increase in the glaring effect, would not be desirable. However, if by means of polarization the apparent brightness of the opposing headlight is cut to almost zero, no matter what its intensity, there seems to be nothing to prevent an increase in the present legal maximum values of candlepower.

There has been a great deal of discussion of the *probable* effect on seeing conditions of the use of polarized light on

motor vehicles, but *very few actual test data have been obtained*. It was the purpose of this investigation to determine quantitatively the effect on seeing conditions of changing the candlepower over a wide range, both with and without polarization. The effect of changing the reflection factor of the pavement and of the object was also investigated, and the result of equipping present cars with polarizing material without increase in lamp size was considered.

APPARATUS AND PROCEDURE.

Tests were made on a model highway, which had been constructed in the Illumination Laboratories, Massachusetts Institute of Technology, in 1935 and which had been used in an investigation of highway lighting by Huse and Neal.[3] It was only necessary to make slight additions to adapt the model for headlight studies. The model was built on a scale of 1 to 24, or one inch to two feet. It was ten feet long and eighteen inches wide, representing, therefore, a roadway 36 feet in width. The observer's vehicle was a chair on wheels; the rear wheels being driven through worm gearing by a d-c. motor.

The vehicle moved on a track approximately 50 feet long, and the tests were conducted by driving this car toward the model highway until the test object could be discerned. The observer could adjust his speed to any value that suited him, and no attempt was made to simulate actual road speed. The glare source and observer's headlamp were similar units, consisting of flash-light reflectors and lamps. Various lamps could be introduced to give the desired range in candlepower.

Three different road surfaces were used: concrete (reflection factor $= 0.25$), smooth macadam ($\rho = 0.05$), wet smooth macadam ($\rho = 0.05$). An international C-shaped standard was used as test object in the investigation. The black object had a reflection factor of approximately 0.02 at normal incidence; the gray, about 0.10; and the white, about 0.50. All test objects were matt.

With the model highway, it was possible to make comprehensive tests by varying road surfaces, positions of the test object with respect to the glare source, reflection factor of objects, and candlepower of both the glare source and

driver's headlamp. Many disturbing factors that would have been present in outdoor tests were eliminated by the use of the scale model.

The following test conditions were used. The glare source was set a distance of five feet (corresponding to one hundred and twenty feet, full-scale) from the observer's eyes. This source moved with the observer and thus gave a constant glare illumination at the eye.* When the headlamp candlepower was changed, the glare-source candlepower was changed correspondingly. The front of the car contained an opaque shield with an opening approximately one inch square, through which the road was observed. This opening was 6 inches (12 ft., full scale) from the right edge of the highway. Monocular vision was used throughout because the binocular effect is not of importance in actual driving. The observer's head was held in position so that the glare source was always in the field of view. The test object was placed in one of three positions across the road. Position I was three feet † from the right side of the road; position II, twelve feet or directly in the observer's line of sight; position III, eighteen feet or in the center of the road. The glare source was twelve feet from the left side of the road.

The illumination on a vertical surface at one hundred and twenty feet from the light source was varied over a range of from 30 lumens per square foot to 0.1 lumen per square foot, which includes a customary value of about 1 lumen per square foot obtained from a 15,000 candlepower beam at approximately 120 feet. Conditions of glare, no-glare, Polaroid [4] with glare, and Polaroid with no-glare were investigated for all the above-mentioned variables. The observer would approach in his vehicle until he could just see the object, and the visibility distance (distance from eye to object) was then measured. One observer was employed in all tests, and consequently the results do not give the average visibility distance for all drivers. However, at least five tests were made for each condition (some two thousand observations in all)

* By "glare illumination" is meant the illumination at the eye, on a plane that is perpendicular to the line of sight.

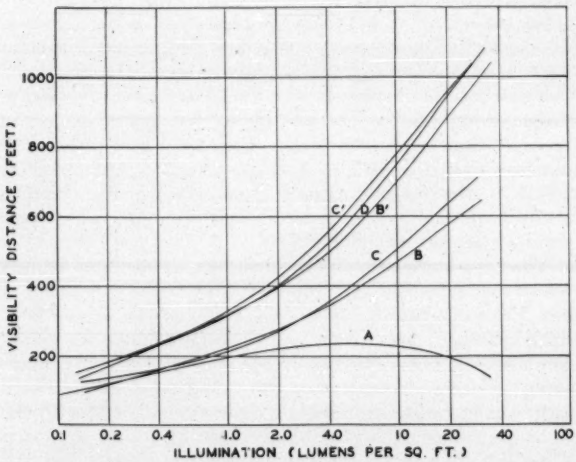
† Full-scale distances will be specified unless otherwise stated.

so the data are a fairly reliable indication of what this individual can do. Moreover, we are interested primarily in the *comparative* distances for various conditions, rather than in the absolute distances. These relationships between the various factors are undoubtedly valid even though the absolute visibility distances may vary with the personal element.

RESULTS.

The three sets of curves shown in Figs. 1, 2, and 3 are average sets of curves giving the general relationship between

FIG. 1.



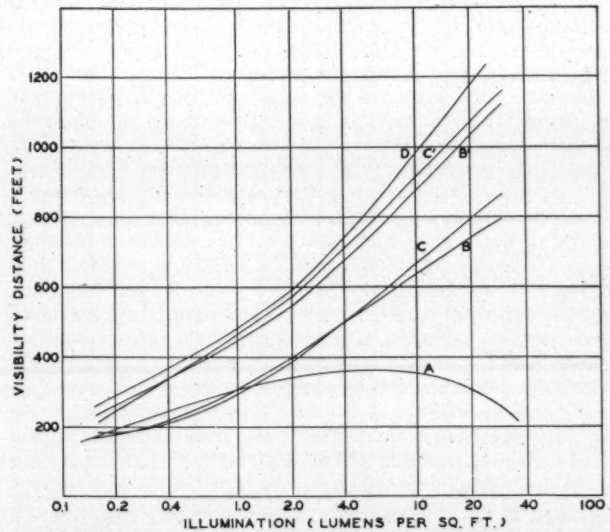
Variation of visibility distance with illumination (Black Test Object). (Beam candlepower = illumination × 14,400). *Curve A*, Glare of opposing headlight is varied to correspond with the increase in observer's headlight candlepower. *Curve D*, no-glare condition. *Curve B*, glare condition with Polaroid. *Curve C*, no-glare condition with Polaroid. (For *B* and *C*, the illumination values were obtained before Polaroid was introduced.) *Curve B'*, glare condition with Polaroid. *Curve C'*, no-glare condition with Polaroid. (For *B'* and *C'*, the illumination values were obtained after Polaroid was introduced.)

the various conditions studied. Each curve is an average of nine individual curves.[5] Since, for a single object, it was found that the road surface and object position made little difference in the visibility distance, it was thought permissible

to average these nine possible combinations in order to summarize the results. One set was obtained for the black object, another for the gray, and a third for the white.

Visibility distance (full-scale) is plotted as a function of the illumination on a vertical plane at right angles to the line

FIG. 2.



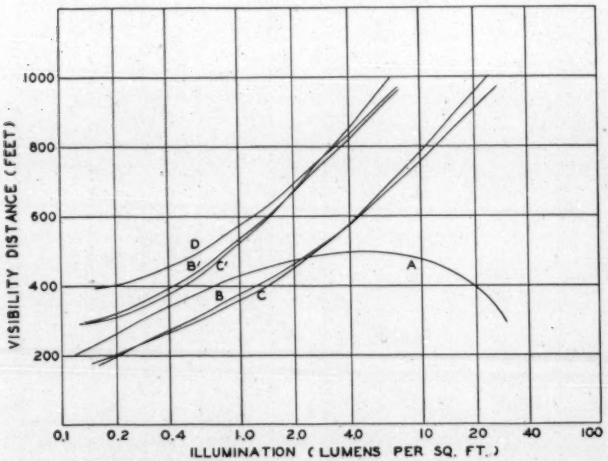
Variation of visibility distance with illumination (Gray Test Object). (Beam candlepower = illumination × 14,400). *Curve A*, Glare of opposing headlight is varied to correspond with the increase in observer's headlight candlepower. *Curve D*, no-glare condition. *Curve B*, glare condition with Polaroid. *Curve C*, no-glare condition with Polaroid. (For *B* and *C*, the illumination values were obtained before Polaroid was introduced.) *Curve B'*, glare condition with Polaroid. *Curve C'*, no-glare condition with Polaroid. (For *B'* and *C'*, the illumination values were obtained after Polaroid was introduced.)

of sight at a distance of 120 feet from the driver's headlight. Since the illumination on this plane is equivalent to the candlepower of the light source divided by the square of the distance, the illumination varies directly as the candlepower. The illumination is also equal to the glare illumination at the

eye, since the intensity of the glare source was always kept equal to that of the driver's headlamp.

Curve *A* represents the condition generally obtained in present practice. With 32 cp. lamps, the illumination at 120 feet is ordinarily about 1.0 lumen per square foot, though this value varies from car to car, depending upon age of the car,

FIG. 3.



Variation of visibility distance with illumination (White Test Object). (Beam candlepower = illumination × 14,400). *Curve A*, Glare of opposing headlight is varied to correspond with the increase in observer's headlight candlepower. *Curve D*, no-glare condition. *Curve B*, glare condition with Polaroid. *Curve C*, no-glare condition with Polaroid. (For *B* and *C*, the illumination values were obtained before Polaroid was introduced.) *Curve B'*, glare, condition with Polaroid. *Curve C'*, no-glare condition with Polaroid. (For *B'* and *C'*, the illumination values were obtained after Polaroid was introduced.)

condition of the lamps, reflectors, battery, etc. The *A* curve shows that as the candlepower of both the observer's headlamp and the opposing glare source is increased, the additional glare is more than compensated by additional illumination until a peak in the visibility distance is reached. Finally, the additional glare becomes so blinding that the visibility distance drops off sharply. This phenomenon has been predicted by most of the recent headlighting investigators. In

a series of visibility tests made by Moon and Warring,[6] the effect of changing the candlepower of the source was studied and although no attempt was made to go above lamps of 32 cp., an equation was derived to show the effect of candlepower on visibility distance. The equation is:

$$\text{Visibility distance} = 178(10)^{-0.0322x}x^{0.454},$$

where x equals headlamp candlepower expressed in terms of normal value (32 cp. lamps). The curve for this equation shows a peak at 195 lamp candlepower, or at about six times the present value. *An inspection of the A curves shows a peak at approximately the same value,* if we consider that 1.0 lumen per square foot corresponds to 32 cp. lamps. *This agreement in candlepower value for maximum visibility distance seems to lend weight to the argument that higher candlepower headlamps are desirable even under the present beam control system.*

The *D* curve represents the present no-glare condition. As is expected, the visibility distance increases continuously with the increase in road illumination. The *B* and *C* curves represent the proposed Polaroid system *without change in lamp size, B* with glare and *C* without glare. The illumination values are those obtained before the Polaroid is introduced. Since Polaroid eliminates practically all glare, *B* and *C* almost coincide. At the higher values of illumination, the glare source appears to become somewhat troublesome and there is a slight spread between the curves. These curves have the general shape of the *D* curve, and indicate that *with present headlamp candlepower* there is no appreciable advantage in introducing Polaroid.

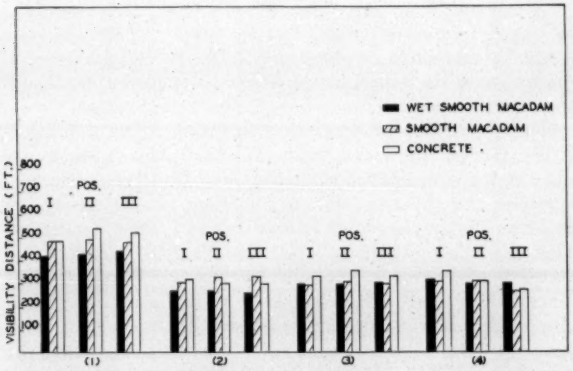
The *B'* and *C'* curves were obtained from the same data as *B* and *C* but were plotted for actual road illumination. The spread between the two sets of curves shows the loss of light caused by the introduction of the polarizing material. The Polaroid used in the tests transmitted approximately 33 per cent of the light.

Curves *A*, *B*, and *C* are seen to be almost coincident at 1.0 lumen per square foot. Thus there is little if anything to be gained by an introduction of the polarized-light system with the retention of the present lamps. There would be a

definite decrease in visibility distance for white objects, which loss is diminished in the case of the gray object, and changed to a slight gain for the black object. However, there is an improvement over the present system if the headlamp candlepower is increased.

Following the curves is a set of bar charts (Figs. 4, 5, 6, and 7), showing the effect of road surface, reflection factor of the objects, and object position. On each chart, the visibility distance at each of the three object positions is shown,

FIG. 4.



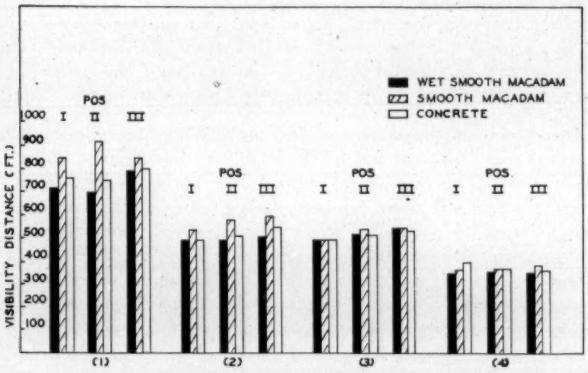
Effect of road surface (unlighted) on visibility distance (Gray Test Object). 1. No glare (No Polaroid). 2. Polaroid (No Glare). 3. Polaroid (With Glare). 4. With Glare (No Polaroid). Illumination at 120 ft. = 1.0 lumens per sq. ft.

also a comparison of no-glare without Polaroid, no-glare with Polaroid, glare with Polaroid, and glare without Polaroid.

Figures 4 and 5 show the effect of road surface, and do not indicate any definite superiority of one surface over another. This might be expected, since the pavement reflects very little light back in the direction of the observer. *The luminosity of the background is low, therefore, and the predominant factor in seeing is the reflection factor of the object itself.*

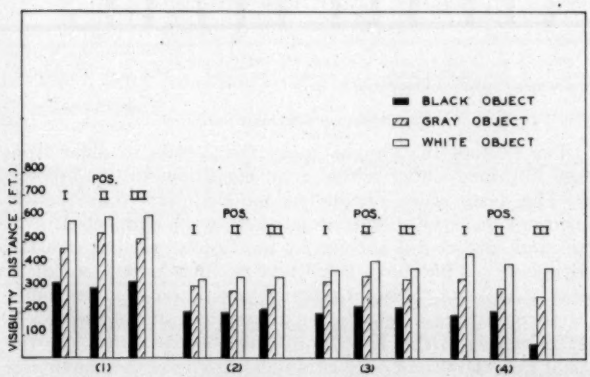
The charts showing the effect of object reflection factor on visibility distance (Figs. 6 and 7) indicate the difficulty of

FIG. 5.



Effect of road surface (unlighted) on visibility distance, (Gray Test Object). 1. No glare (No Polaroid). 2. Polaroid (No Glare)l. 3. Polaroid (With Glare). 4. With Glare (No Polaroid) Illumination at 120 ft. = 5.0 lumens per sq. ft.

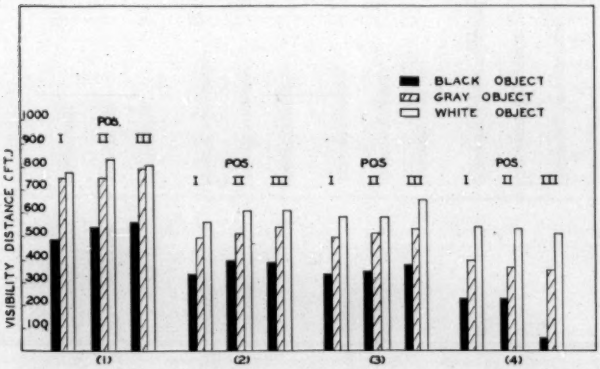
FIG. 6.



Effect of reflection factor of object on visibility distance (Concrete pavement). 1. No glare (No Polaroid). 2. Polaroid (No Glare). 3. Polaroid (With Glare). 4. With Glare (No Polaroid). Illumination at 120 ft. = 1.0 lumens per sq. ft.

discerning black objects. There is a marked improvement in visibility distance for the gray objects ($\rho = 0.10$), and a further increase for white ($\rho = 0.5$). In practice, however, it is unusual for the reflection factor of clothing worn by pedestrians to exceed 0.10. In most cases the reflection factor of clothing is approximately the value of the black object ($\rho = 0.02$).[7]

FIG. 7.



Effect of reflection factor of object on visibility distance, (Concrete pavement). 1. No glare (No Polaroid). 2. Polaroid (No Glare). 3. Polaroid (With Glare). 4. With Glare (No Polaroid) Illumination at 120 ft. = 5.0 lumens per sq. ft.

POSSIBLE LIMITATIONS.

The factors that might cause the results to differ from those obtained under actual road conditions are as follows: (1) The tests were conducted indoors, and consequently variations in atmospheric conditions were eliminated. (2) The road surface did not extend to the observer but was discontinuous. Therefore, there was no illuminated pavement directly in front of the observer as would be the case under actual conditions. (3) The maximum intensity of the opposing beam was in the direction of the observer's eye. In the actual case the driver only gets short flashes of this maximum glare, so the present results apply to the worst glare conditions. (4) The glare source was set at a fixed distance (one

hundred and twenty feet) from the observer. In actual practice, the glare is gradually built up as the cars approach, and is then suddenly removed entirely. (5) In this investigation the observer was allowed a period in which to adapt his eye to the glare illumination. In the actual case, this adaptation period is usually not allowed. (6) The effect of fatigue was eliminated by allowing the observer to work for only short periods. In actual road driving, fatigue may be a vital factor. (7) The speed of the observer's vehicle was in no way comparable to actual road speeds, except when the reduced scale is considered. However, recent investigators [6, 8] have shown that visibility distance is not greatly affected by automobile speed.

The values of visibility distance obtained in this investigation are about 50 per cent. greater than those obtained by Moon and Warring [7] in their tests. However, the conditions of test were not quite the same and only one observer was used in these tests while Moon and Warring used several observers. The data obtained in road tests by Roper and Howard [9] approximate the values of visibility distance (upon application of the 50 per cent. "observer-consciousness" factor) presented in this paper. However, the fact that the observer had to signify the direction of the slot in the C-shaped standard object should have decreased the visibility distances obtained here, to compensate somewhat for "observer-consciousness."

CONCLUSIONS.

From the Pedestrian's Viewpoint.

No Polaroid.

1. Visibility distance is so nearly independent of road surface that the pedestrian is in equal danger on any road surface.
2. The ligher the clothing worn, the greater the visibility distance, white in most cases giving 75 per cent. to 100 per cent. greater visibility distances than black. For the object in the position nearest the glare source, the visibility distance for white is at least five times as great as that for black.

With Polaroid.

1. The installation of Polaroid would cause the pedestrian to suffer from additional glare, but would aid him by making him more discernible to automobile drivers.

From the Motorist's Viewpoint.

No Polaroid.

1. It is desirable to increase the candlepower of present systems above 32. The additional visibility distance may be only fifty feet for the worst glare condition, yet even that increase may be important.

With Polaroid.

1. The introduction of Polaroid on all cars, *with a proper increase in candlepower*, would give excellent results.
2. There is little, if anything, to be gained by the introduction of Polaroid *with lamps of the present candlepower*. There would be a definite decrease in visibility distance for white objects, which loss is diminished in the case of the gray object, and changed to a slight gain for the black object.
3. To attain the present no-glare visibility distance with Polaroid, it seems necessary to increase the source candlepower to three to four times its present value. Any improvement in reflector efficiency or any decrease in the loss of light through the lens system would, of course, lessen the necessary candlepower.

The Author wishes to acknowledge the help of Parry Moon of the Department of Electrical Engineering in the general supervision which he gave the entire investigation. The Author also wishes to acknowledge the invaluable aid in conducting the tests contributed by Mr. Leslie L. Miller.

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3. E. L. HUSE AND F. M. NEAL, "Investigation of Satisfactory Highway Lighting," M. I. T., E. E. Thesis, 1935.

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DICKINSON AND ALLEN, "Conclusions from Headlight Research," *S. A. E., Trans.*, **27**, 1932, p. 339.
9. ROPER AND HOWARD, "Seeing with Motor Car Headlamps," *I. E. S. Trans.* **33**, 1938, p. 417.

Paul Bunyan Lumber Pile.—If all the lumber cut in the United States for about the last 135 years were in a single solid pile it would make a cube almost exactly 1 mile in each dimension according to a recent calculation by the Federal Forest Service. The pile would be more than four times the height of the Empire State Building (1,248 feet). As much lumber has been cut in the last 35 years, according to Forest Service estimates, as in the preceding 100 years.

R. H. O.

Developed and Potential Water Power of the World.—The capacity of the water wheels in the constructed plants of the world, according to estimates made by the Geological Survey, U. S. Dept. of the Interior, was 23,000,000 horsepower in 1920, 29,000,000 horsepower at the end of 1923, 33,000,000 horsepower at the end of 1926, 46,000,000 horsepower at the end of 1930, 55,000,000 horsepower at the end of 1934, 60,000,000 horsepower at the end of 1936, and 64,000,000 horsepower at the end of 1938, an increase of nearly 180 per cent. in 18 years. The ten countries leading in developed water power and the installed capacity, in horsepower, of water wheels in each, according to these estimates were as follows: First, United States, 17,949,000; second, Canada, 8,191,000; third, Italy 6,000,000; fourth, France, 5,400,000; fifth, Japan, 4,800,000; sixth, Germany, 4,000,000; seventh, Norway, 3,000,000; eighth, Switzerland, 2,800,000; ninth, Sweden 2,200,000; tenth, Union of Soviet Socialist Republics, 1,630,000. A statement of the capacity of machinery installed in the different countries, however, does not give a complete picture. For example, in such countries as Canada and Norway, which have abundant water-power resources, the electrical output of the water wheels is greater per horsepower installed than in other countries, such as France and Germany, whose resources are not so great. In Canada and Norway only the best sites are utilized, and at these sites only so much machinery is installed as can be operated throughout a large part of the year with the water available, whereas in countries where the demand for power is great and the potential water-power resources comparatively small, machinery is installed to use water power that is available for only a small part of the year, power for the remaining period being supplied by steam.

R. H. O.

THE SCIENCE OF BALANCING AN IMPEDANCE BRIDGE.

BY

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Massachusetts Institute of Technology.

I. INTRODUCTION.

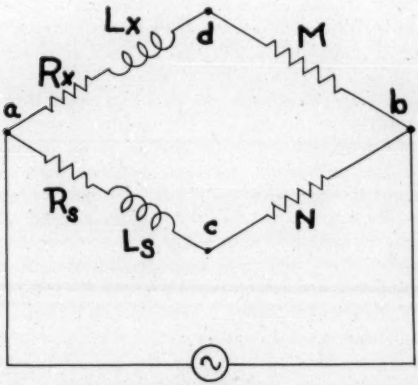
The property of being easily and quickly balanced is a characteristic which should be possessed by any impedance bridge if it is to be of maximum utility, yet there seems to be no published analysis * which can be used to determine the presence or lack of this ability. A criterion which has been recommended by Ferguson [1] is that the adjustment which balances out one component of the unknown should be independent of the adjustment which balances out the other component of the unknown. Bridge circuits which meet this requirement can be quickly balanced, but there are some very useful circuits that do not fulfill this requirement which can nevertheless be balanced with a fair degree of rapidity. It is the purpose of this paper to present an analysis of the balancing of an impedance bridge which gives a measure of the rapidity of attaining balance. Several other topics, such as shifting balances, trivial balances, choice of adjustments and initial setting of these adjustments, are also discussed.

The analysis is based upon locus diagrams.[2] These show the variations which occur in the potential difference between the detector terminals when the various impedances in the bridge arms are varied. In most bridge circuits, the loci are parts of circles. The analysis divides itself into two parts: (1) the attainment of approximate balance, in which the curvature of the loci must be considered, and (2) the attainment of a precise balance from an approximate balance, in which the region being studied is so limited that the loci can be considered as straight lines. For the discussion of the

* *Note:* Since the completion of this paper, it has been called to the attention of the author that there is a treatment of some of the features of the same subject in B. Hague, "A.C. Bridge Methods," 4th edition, Pitman, 1938, pages 37–45, 76–81 and 299–305.

first of these parts, it is very convenient to have a definite circuit to act as a vehicle for the development of the analysis. For this purpose, the Maxwell inductance bridge (Fig. 1) is used because (1) its circuit is simple, and (2) in spite of its simplicity, it may be difficult to balance under certain conditions ("shifting balance"). The same method of analysis which is used in this example can of course be applied to any bridge circuit. The second part of the analysis is given in

FIG. 1.



Maxwell bridge.

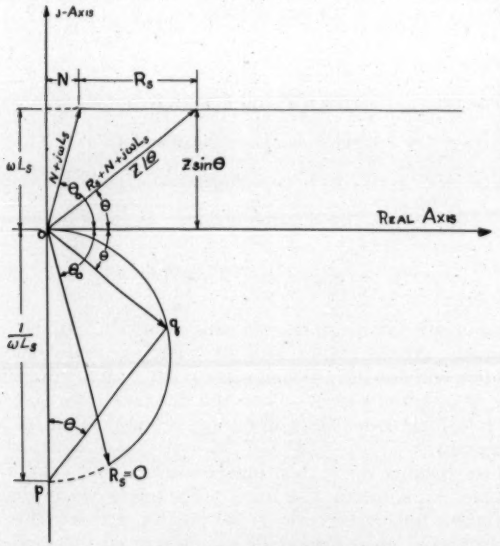
such a form that the results can be directly applied to any bridge circuit. The analysis gives a measure of the rapidity with which balance of any desired precision is attained. This measure can be easily obtained from the balance equation of the bridge.

Throughout the analysis, it is assumed that the input impedance of the detector is high so that it draws a negligible current. This sacrifices but little useful generality since vacuum tube amplifiers are now so commonly used as bridge detectors. It is also assumed that the potential difference between the source terminals of the bridge is constant.

II. LOCUS DIAGRAMS.

The fundamental problem of the locus diagram is this: given a circuit, find the loci for the ends of the various voltage and current vectors as one of the variables in the circuit traverses its range of adjustment. As a specific example, let R_s in the Maxwell bridge of Fig. 1 be varied from zero to

FIG. 2.



Development of loci for Maxwell bridge.

infinity. What is the locus of the potential difference between c and d?

In this specific problem it has been assumed that the potential difference between a and b is independent of the value of R_s. Consequently, the adjustment of R_s has no effect upon conditions in the adb branch of the bridge, and the series circuit acb is the only branch which need be considered. As R_s is increased from zero to infinity the im-

pedance of the branch *acb* starts at $N + j\omega L_s$, increases to $R_s + N + j\omega L_s$ and finally becomes $\infty + N + j\omega L_s$, as is shown graphically in Fig. 2. Under these conditions, the locus of the impedance is a straight line, parallel to the axis of reals, starting at $N + j\omega L_s$ and ending at $+\infty$.

In order to find the locus of the current through the branch *acb*, it is convenient to find the admittance, $Y = \frac{I}{Z}$, since $I = YV$. If the angle of Z is θ, the angle of Y is $-\theta$. The magnitude of Y is $\frac{I}{Z}$.

The relation between Z and θ is

$$Z \sin \theta = \omega L_s = \text{a constant}, \qquad (1)$$

because the locus of Z is a horizontal line. Substituting $Z = \frac{I}{Y}$ in Eq. (1), the relation between Y and θ becomes

$$\frac{Y}{\sin \theta} = \frac{I}{\omega L_s} = \text{a constant}. \qquad (2)$$

A geometric interpretation of this equation can be easily obtained. At the end of Y, draw a line perpendicular to Y. This line will cut the j-axis at some point p, and will make an angle θ with the j-axis. Then the distance from the origin o to p is $Y/\sin \theta$, which from eq. (2) is equal to $1/\omega L_s$, which is constant.

The distance op is then independent of the value of the variable, R_s, so point p is fixed. The angle oqp is always a right angle by construction so the point q, which is the tip of the vector Y, must always lie somewhere on the semi-circle which has op as a diameter. When $R_s = 0$, the angle of Y is $-\theta_0$, and since θ is never larger than θ_0, the angle of the admittance never exceeds $-\theta_0$. This is indicated by showing part of the semi-circle of Fig. 2 as a dotted line. When $R_s = \infty$, Z is infinite, so Y is zero.

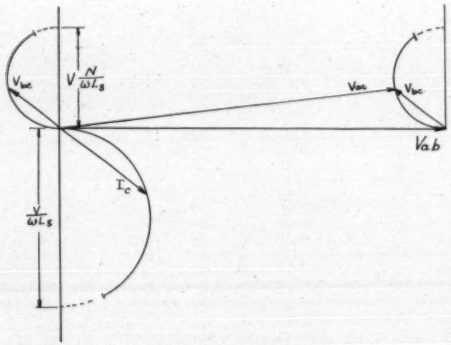
With the aid of this locus, the locus of I_s can be readily determined by multiplying the locus of Y by V_{ab}. Since V_{ab} has a zero angle, this multiplication is merely a change in scale, as is shown in Fig. 3. If the angle of V_{ab} had been θ

different from zero, the locus of Y would have to be rotated by an angle θ and then changed in scale in order to get the locus of I_c. The potential difference between b and c is given by

$$V_{bc} = -I_c N.$$

The locus of V_{bc} can be readily obtained by multiplying the locus of I_c by N and rotating it 180°, because of the negative sign. The locus of V_{ac} can be found by moving V_{bc} with its

FIG. 3.



Loci for I_c and V_{bc}.

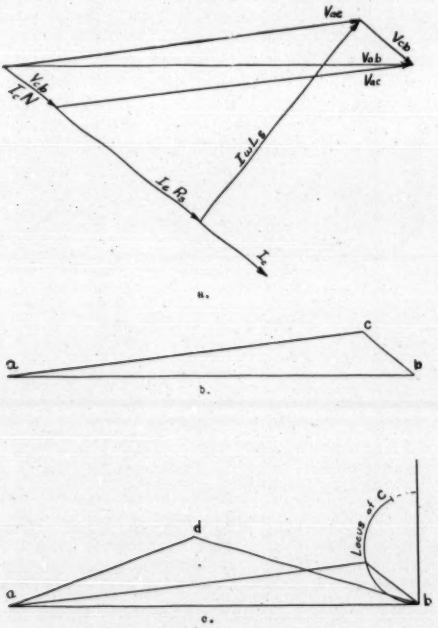
locus to the end of V_{ab}. The diagram then expresses the equation,

$$V_{ac} = V_{ab} + V_{bc}.$$

The vector diagram of the branch acb is shown in Fig. 4a, using arrowheads to denote which one of the two possible directions along each of the straight lines is the correct one. Figure 4b shows a method of lettering vector diagrams which is much simpler for use in locus diagrams. The ends of the vectors are marked with letters corresponding to the junction points in the circuit. The potential difference between any pair of terminals, such as b and c, is the length of the line joining the corresponding points, b and c, in Fig. 4b. If the

potential from b to c is desired in contrast to the potential from c to b, the vector is considered to be directed from b to c in Fig. 4b, and vice versa. In this way there is only one location on the vector diagram for any given vector, which

FIG. 4.



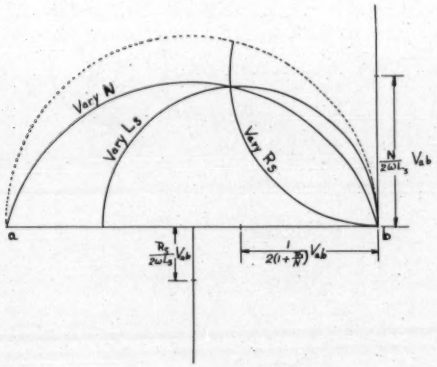
Vector diagrams for Maxwell bridge.

is not true in the diagram of Fig. 4a, where any vector can be moved about at will, as long as it is not rotated or changed in length. A great advantage arises from this uniqueness, for once a point is located on a diagram of the type of Fig. 4b, the potential difference between it and any other point in the diagram can be very readily found. The position of any

point such as c in Fig. 4b is herein called the potential of c, to avoid confusion with the actual physical position of the corresponding point c in the circuit diagram.

The locus of V_{bc} found in Fig. 3 can be readily transferred to the diagram of Fig. 4b, as is shown in Fig. 4c. The potential of d may be plotted on the diagram of Fig. 4c by any one of several ways suggested by the theory of alternating

FIG. 5.



Loci of detector point potential.

current circuits. One way is to calculate the two angles

$$\angle\, abd = \tan^{-1}\frac{\omega L_x}{R_x + M} \tag{4}$$

and

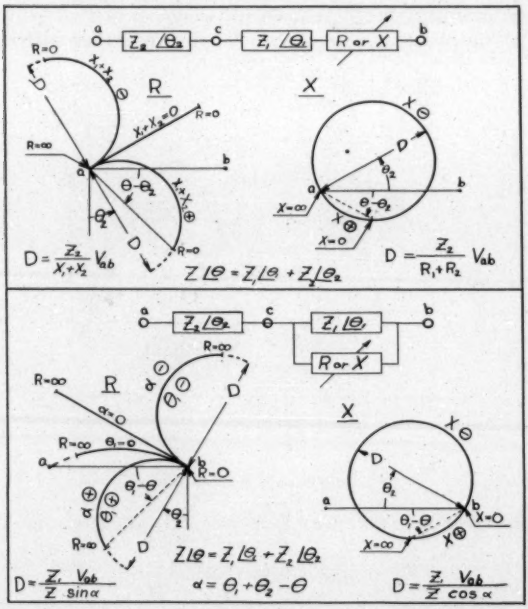
$$\angle\, bad = \tan^{-1}\frac{\omega L_x}{R_x} - \tan^{-1}\frac{\omega L_x}{R_x + M}. \tag{5}$$

With these angles the potential of d may be determined. Then the locus of V_{dc} is found by taking d as the origin, and using the locus of the potential of c as the locus of the tip of V_{dc}.

Similar developments may be used to determine the locus of the potential of c when either L_x or N is varied. The resulting loci are shown in Fig. 5, in which the locations of the

centers are given. If, in Fig. 5, N is replaced by M, R_s by R_x and L_s by L_x, the diagram shows the locus of the potential of d for variations in M, R_x and L_x.

FIG. 6.



Generalized loci for the potential of c. The loci themselves are in heavy lines. Wherever the dimension lines for an angle have only one arrowhead, the angle is positive, in the direction shown, and the angle is negative if it is in the direction opposite to the direction shown. The starting line for all angles is the arrowless end of the dimension line.

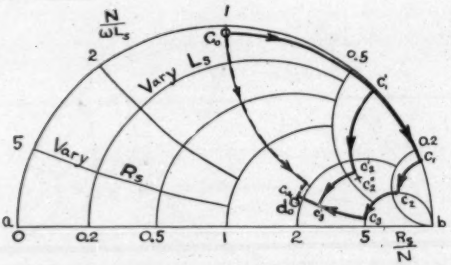
Loci for a few of the commonly used bridge combinations are shown in Fig. 6, in generalized form. Only one branch of a bridge is given in each case, and specific bridge combinations can be studied by putting together, as is done in Sections IV and V, the loci for the two branches that are used in the bridge under consideration.

III. THE ATTAINMENT OF APPROXIMATE BALANCE.

With the loci available, the operation of balancing the Maxwell bridge can be readily studied. In order to present a vivid contrast two cases are considered, one in which R_s and L_s are varied and another in which R_s and N are varied. For this purpose, in Figs. 7 and 8 there are drawn a series of loci which act as circular coördinates for the potential of c. These axes are given scales in terms of ratios, so that the scales will fit any values of the parameters.

Referring to Fig. 7 for the first case, let it be assumed that the bridge is set so that the initial potentials of c and d are

FIG. 7.



Loci for variables R_s and L_s.

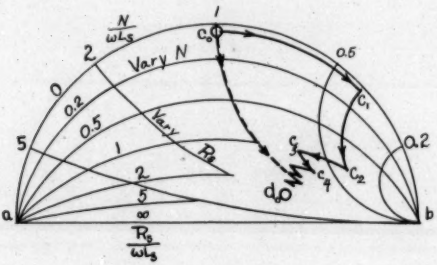
c_0 and d_0 respectively. Then let L_s be increased until V_{cd} is a minimum. In this operation, the potential of c moves along the heavy solid line from c_0 to c_1 as is indicated by the arrows. Then let R_s be increased to bring V_{cd} to a smaller minimum, moving the potential of c from c_1 to c_2. By successive adjustments V_{cd} becomes smaller and smaller as the potential of c is moved from c_2 to c_3 to c_4 which is an approximate balance. From this point on, the balancing adjustments must be studied on an enlarged scale, which is done subsequently.

An experimental check upon this procedure, using an amplifier-telephone combination as a detector and a 1000 c.p.s. source, showed that balance was approached along the lines c_1', c_2', c_3', c_4. The potential difference between d_0 and c_1' is about 6 per cent. larger than that between d_0 and c_1. This

is within the experimental limits, however, since the average ear can not detect a change in voltage applied to the telephones of less than about 10 per cent. (1 db.). After c_1' was obtained experimentally, R_s was varied until V_{d_0c} reached a new minimum. Theoretically c_2'' should have been chosen, but c_2' was selected experimentally. The difference between $V_{d_0c_2''}$ and $V_{d_0c_2'}$ is much less than the experimental error. Likewise the error in selecting c_3' was much less than 10 per cent.

It is interesting to note that every experimental point is undershot, i.e., the variable was not changed quite enough to

FIG. 8.



Loci for variable R_s and N.

reach the minimum V_{cd}. This seems to be an advantage here, causing $V_{c_2'd_0}$ to be smaller than $V_{c_2d_0}$, and $V_{c_3'd_0}$ to be smaller than $V_{c_1d_0}$. However, the next adjustment brings the theoretical and experimental values of c to the same potential, c_4, so the apparent advantage is lost. It should be noted that if R_s had been adjusted first instead of L_s, approximate balance would have been attained more rapidly along the heavy dotted lines.

As a contrast to this rather rapid attainment of approximate balance, Fig. 8 shows an example of conditions when the variables are N and R_s. If the heavy line, an experimental one, is followed, the potential of c zig-zags towards d_0. Many adjustments are required to attain approximate balance. As

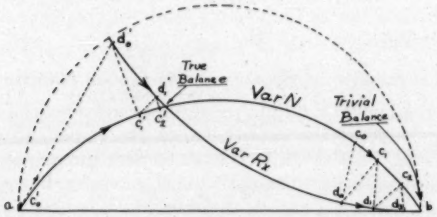
c approaches d_0, the loci become more nearly parallel, and adjustment becomes more and more difficult. If R_s is the first adjustment to be made, some improvements in the situation result, but there is still plenty of zig-zag path to be traversed.

This sort of approach to balance is sometimes called a "shifting balance," because the values of the variables at successive minima continually increase or decrease, depending on circumstances. It is very troublesome, because of the large number of adjustments which must be made to attain a precise balance. (See Section VI.)

IV. TRIVIAL BALANCES.

Another interesting result which can be obtained from this type of analysis concerns the attainment of a trivial

FIG. 9.



Trivial and true balance.

balance. Such a condition can arise in the Maxwell bridge if R_x and N are used as the variable. They might be so used if the unknown had a higher Q than the standard, necessitating the introduction of a resistance in series with the unknown.

When R_x and N are thus used, the potentials of both c and d are variable along the loci shown in Fig. 9. Suppose that the initial potentials of c and d are at c_0 and d_0 respectively. Then if N is varied first the potential of c moves from c_0 to some value such as c_1. An adjustment of R_x moves the potential of d to d_1. Subsequent adjustments move the potentials of both c and d towards b as a balance point. This

is, however, a trivial balance, for then $R_x = \infty$ and $N = 0$, which gives

$$L_x = L_s \frac{M}{N} = \infty \tag{6}$$

and

$$R_x = R_s \frac{M}{N} = \infty. \tag{7}$$

The first of these is of course incorrect.

If, however, the initial settings are made with R_x as small as possible and $N = \infty$ (d_0' and c_0'), the true balance can be reached. N is first lowered, moving the potential of c to c_1'. Then R_x is raised until the potential of d reaches d_1'. Successive adjustments cause the potentials of both c and d to approach the true balance position.

The analysis shows that a trivial balance can be avoided by a proper choice of starting conditions for the variables, which in turn can be found by a study of the locus diagrams for the bridge.

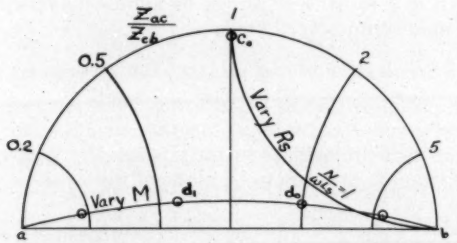
V. ADJUSTMENT OF THE RATIO ARMS FOR GOOD SENSITIVITY.

The fundamental requirement for a sensitive bridge is that the magnitude of the ratio between the impedances of the two arms in the same branch shall be near unity. When the ratio is unity, the most sensitive bridge results, but when the ratio is between 1/3 and 3, the sensitivity is never less than 60 per cent. of the maximum.[3] If the ratio is between $\frac{1}{\sqrt{3}}$ and $\sqrt{3}$, the sensitivity is never less than 84 per cent. of the maximum. The locus diagram analysis helps to show how to proceed in order to obtain a sensitivity not too far below maximum.

In the Maxwell bridge previously discussed, the ratio V_{ac}/V_{cb} is the same as the ratio Z_{ac}/Z_{cb}. When these ratios are near unity, the potential of c will then be near the perpendicular bisector of ab, as is shown in Fig. 10. The loci for other values of the ratio are also shown in Fig. 10. They are circles whose centers are on the projection of ab, as can be shown by analytic geometry. It is desired so to operate the

bridge that the final balance will be achieved with the potentials of c and d as near the locus for $\frac{Z_{ac}}{Z_{cb}} = 1$ as is convenient. One way of doing this is to set R_s as low as possible, and then to set either N or L_s so that $N = \omega L_s$. This places the potential of c at c_0 in Fig. 10, which is very nearly on the locus for $\frac{Z_{ac}}{Z_{cb}} = 1$. Then M is varied, which moves the potential of d along a locus such as that shown in Fig. 10. Of course the exact location of this locus depends on $\frac{R_x}{\omega L_x}$, as may be seen

FIG. 10.



Loci of the potential of c for constant values of Z_{ac}/Z_{cb}.

from Fig. 5. If M can be adjusted in small steps, the potential of d can be brought close to the locus for $Z_{ac}/Z_{cb} = 1$. Sometimes, however, it is quite satisfactory to have M adjustable in fairly large steps, preferably in approximately logarithmic ones. Such a resistor might have resistances of 10, 100, 1000, 10,000, and 100,000 ohms, or 10, 30, 100, 300, and 1000 ohms. If the first of these resistors is used, when M is adjusted, the potential of d is fairly certain to fall between the loci for $\frac{Z_{ac}}{Z_{cb}} = \frac{1}{\sqrt{10}} = 0.316$ and $\sqrt{10} = 3.16$. Likewise, with the second of the above resistors, the potential of d is fairly certain to fall between the loci for $\frac{Z_{ac}}{Z_{cb}} = \frac{\sqrt{3}}{10} = 0.55$ and $\frac{\sqrt{10}}{3} = 1.83$.

In the experimental check on the examples of part III, the second of the above resistors was used for M. The possible potentials of d are indicated on Fig. 10 by small circles, and the one marked d_0 was experimentally chosen as giving the lowest value of V_{cd}. Notice that $V_{c_0 d_1}$ is actually about 2 per cent. smaller than $V_{c_0 d_0}$, which means that the ear could not distinguish between them, so the choice of d_0 rather than d_1 was arbitrary.

The analysis can, of course be extended to other circuits, or to other conditions in this circuit. For example, the desire to get a scale which is direct reading might dictate that N be the one to be adjusted in large steps. Then N could be calibrated as a range selector, or as a multiplier switch, as is done in many commercial bridges.

VI. THE ATTAINMENT OF A CLOSE BALANCE FROM APPROXIMATE BALANCE.

Once an approximate balance has been reached, the potentials of c and d are so close together that the curvature of the loci in their immediate vicinity is small. This enables a relatively simple analysis to be made on the basis of straight-line loci.

Consider a general situation in which there are two variables, A and B, which govern the potential of c. The potential of d is fixed. The loci of the potential of c for variations in A are assumed to be parallel straight lines. For each of these lines, B has a definite value. The loci of the potential of c for variations in B are likewise assumed to be parallel straight lines, for each of which there is a definite value of A. These two sets of loci intersect each other at an angle α, and are shown in Fig. 11.

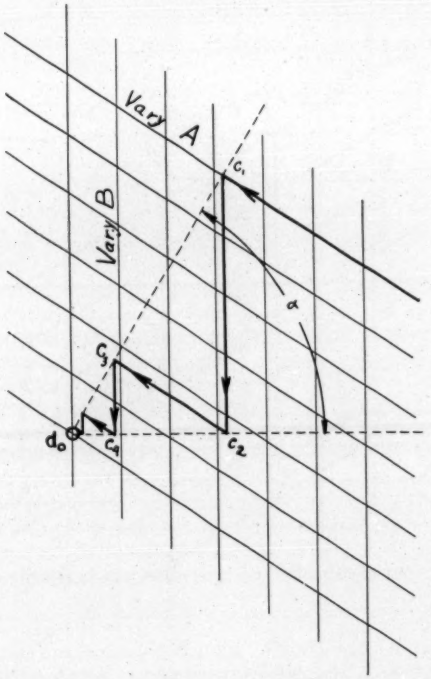
As the variables A and B are adjusted in succession, the potential of c approaches that of d along the zig-zag path shown in Fig. 11, provided each adjustment is made to an exact minimum. From this, there can be determined a quantity, K, which is the fractional reduction in detector voltage per adjustment on the bridge. Thus:

$$K = \frac{V_{c_2 d_0}}{V_{c_1 d_0}} = \frac{V_{c_3 d_0}}{V_{c_2 d_0}} = \cos \alpha, \qquad (8)$$

so that the nearer the angle of intersection of the loci is to 90 degrees, the quicker a close balance is obtained.

In making the adjustments for balance, each minimum

FIG. 11.

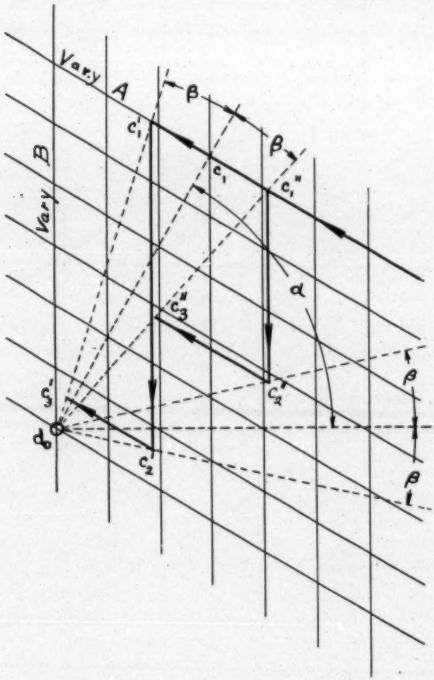


The attainment of precise balance, assuming perfect adjustment of each variable.

has a certain degree of uncertainty about it which is inherent in the process. This uncertainty can be expressed in terms of an angle β, shown in Fig. 12. The greatest reduction in detector voltage per adjustment occurs when the adjustments

overshoot the minimum to the edge of the uncertainty region, as shown by the path c_1', c_2', c_3'. Likewise, the smallest reduction per adjustment is obtained when the adjustments

FIG. 12.



The attainment of precise balance, allowing for uncertainty of adjustment of the variables.

undershoot the minimum to the edge of the uncertainty region, as shown by the path c_1'', c_2'', c_3''. By applying the law of sines to the triangle $d_0c_1'c_2''$, the reduction per adjustment for

the first case becomes

$$K = \frac{V_{c_2'd}}{V_{c_1'd}} = \frac{\sin(90° - \beta - \alpha)}{\sin(90° - \beta)} = \frac{\cos(\alpha + \beta)}{\cos\beta} \quad \text{(overshoot)}. \quad (9)$$

When $\alpha + \beta$ become greater than 90°, c does not zig-zag towards d_0, but approaches it through a path which "spirals" around d_0. K is then given by the negative of Eq. (9), as can be shown by a similar analysis.

For the second case, if $\alpha > 2\beta$,

$$K = \frac{V_{c_2''d}}{V_{c_1''d}} = \frac{\cos(\alpha - \beta)}{\cos\beta} \quad \begin{matrix}\text{(undershoot)} \\ (\alpha > 2\beta)\end{matrix}. \quad (10)$$

When α becomes less than 2β, the terms "undershoot" and "overshoot" lose their meaning, because the adjustments must be moved in one direction to reach one uncertainty limit, and in the other direction to meet the other uncertainty limit.

When an amplifier telephone combination is used as the detector an approximate value of β can be obtained from the fact that the ear can detect differences in sound level of about 1 db. This is a voltage ratio of 0.89, which is the cosine of an angle of 27 degrees. If adequate amplification is available, so that the threshold of hearing is not approached, it seems reasonable to expect that settings could be made within the middle half of the region of minimum signal. The corresponding value of 13.5 degrees is assigned to β when an amplifier-telephone combination is used as the detector. Using this value, the limits of the reduction per adjustment are

$$K = 1.03 \cos(\alpha \pm 13.5°). \quad (11)$$

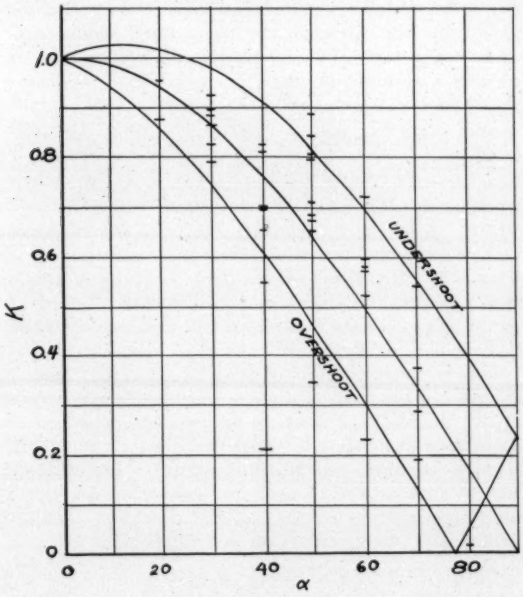
These limits are plotted in Fig. 13. On the same coördinates are plotted a group of points experimentally determined by two observers at 1000 c.p.s. using the Maxwell bridge circuit which was used as an example in Section III.

Most of these experimental points fall within the predicted limits. However, there are 21 points on the undershoot side of the center line, and 13 points on the overshoot side. In order to obtain a low value of K, it would be beneficial to

purposely overshoot the minimum a bit, if α is less than 77·5°, but the tendency shown by the above figures is in the opposite direction.

The number of adjustments that are required to reduce the detector voltage to any given proportion, p, of the applied

FIG. 13.



The relation between K, the reduction of detector voltage per adjustment; and α, the angle at which the loci for the variables intercept each other. The overshoot and undershoot curves as plotted for β, the uncertainty angle, equal to 13.5 degrees. The experimental points were obtained with an amplifier telephone combination.

bridge voltage can be calculated from K. The first few adjustments are not treated by this theory, because the adjustments are so large that the curved nature of the loci makes it inapplicable. However, when the detector voltage reaches about a tenth of the bridge voltage, the theory begins to

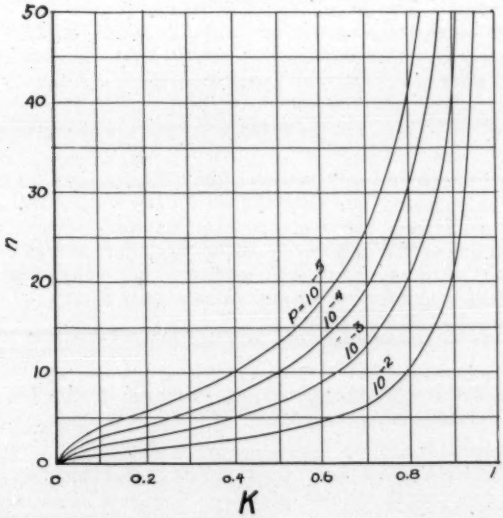
apply. The number of adjustments, n, required to reduce the detector voltage from 0.1 V_{ab} to pV_{ab} can be found by solving the equation

$$0.1\,V_{ab}K^n = pV_{ab}. \tag{12}$$

The solution gives

$$n = \frac{\log 10 + \log p}{\log K}. \tag{13}$$

FIG. 14.



The relation between n, the number of adjustments required to reduce the detector voltage from 0.1 times the applied voltage to p times the applied voltage, and K, the reduction in detector voltage per adjustment.

This relation between n and K is shown in Fig. 14. for different values of p. It supports Ferguson's statement that a bridge in which the adjustments are independent is an easy one to balance, for in such a bridge, α is 90°, which corresponds to values of K between 0.23 and 0, which in turn give the lowest number of necessary adjustments. However, the number of

necessary adjustments does not begin to increase rapidly until K becomes larger than 0.5 to 0.7, depending upon the sensitivity that is desired in the bridge. On the average, a K of 0.7 corresponds to an intersection angle of about 45 degrees, so that bridges in which the intersection angle is 45 degrees or more ought to be useful, especially if the operator deliberately overshoots the minima somewhat.

In the example of Fig. 8, the curve on which $R_s/\omega L_s = 1$ intersects all the curves of the other set of loci at an angle of 45 degrees. The useful region of this particular bridge is that in which the potentials of c and d lie above this curve at balance. In other words, this means that the bridge is useful when

$$\frac{\omega L_x}{R_x} = Q_x \geqslant 1. \tag{14}$$

In the example of Fig. 7, however, the curves always intersect at right angles, so the bridge is good for any values of Q_x.

The difference between these two examples lies solely in the choice of the parameters to be adjusted, and yet one bridge is satisfactory only if Q_x is greater than unity, whereas the other is satisfactory for any value of Q_x.

VII. THE DETERMINATION OF α FROM THE BALANCE EQUATION.

The value of α can be readily determined from the balance equation of the bridge. Under any condition of a bridge, the potential difference between c and d is

$$V_{cd} = V_{ab}\frac{Z_1Z_4 - Z_2Z_3}{(Z_1 + Z_2)(Z_3 + Z_4)} = V_{ab}\frac{H}{D}. \tag{15}$$

The balance equation is then the condition that gives $V_{cd} = 0$, which is

$$H = Z_1Z_4 - Z_2Z_3 = 0. \tag{16}$$

Let there be two variables, A and B, which are adjusted in order to give precise balance of the bridge. Then in Fig. 11 the lines of Variable A are parallel to the complex number $\frac{\partial V_{cd}}{\partial A}$ taken at balance. Likewise the lines of Variable B are

parallel to the complex number $\frac{\partial V_{cd}}{\partial B}$ taken at balance. Consequently, the angle between these two complex numbers is α.

Differentiating the equation for V_{cd} with respect to A, there results

$$\frac{\partial V_{cd}}{\partial A} = \frac{V_{ab}}{D^2}\left(D\frac{\partial H}{\partial A} - H\frac{\partial D}{\partial A}\right). \tag{17}$$

At balance, H is zero, so the second term of this equation drops out, leaving

$$\left.\frac{\partial V_{cd}}{\partial A}\right|_{\text{at balance}} = \frac{V_{ab}}{D}\frac{\partial H}{\partial A}. \tag{18}$$

In a like manner, when B is varied,

$$\left.\frac{\partial V_{cd}}{\partial B}\right|_{\text{at balance}} = \frac{V_{ab}}{D}\frac{\partial H}{\partial B}. \tag{19}$$

The angle α is then the angle of $\frac{V_{ab}}{D}\frac{\partial H}{\partial A}$ minus the angle of $\frac{V_{ab}}{D}\frac{\partial H}{\partial A}$. Since the term $\frac{V_{ab}}{D}$ appears in both of these expressions, its angle is eliminated in the subtraction, leaving the relation

$$\alpha = \text{Angle of}\frac{\partial H}{\partial A} - \text{Angle of}\frac{\partial H}{\partial B}, \tag{20}$$

which is a relatively simple relation. Once α is determined, the curves of Figs. 13 and 14 can be used to give the number of adjustments necessary to attain balance of any degree of precision.

As an example of the ease of using this expression, consider the bridge of Fig. 1. Here the balance equation is

$$H = N(R_x + j\omega L_x) - M(R_s + j\omega L_s) = 0. \tag{21}$$

Let the variables be N and R_s. Then

$$\frac{\partial H}{\partial N} = R_x + j\omega L_x = \sqrt{R_x^2 + \omega^2 L_x^2}\,\underline{/\tan^{-1}\frac{\omega L_x}{R_x}} \tag{22}$$

and

$$\frac{\partial H}{\partial R_x} = -M \angle 0, \tag{23}$$

whence

$$\alpha = \tan^{-1}\frac{\omega L_x}{R_x}, \tag{24}$$

which agrees with the results of part VI.

VIII. SUMMARY.

Usually the operator of an impedance bridge has little or no idea of the actual process by which the detector voltage is brought to zero. By drawing locus diagrams for the bridge, the process of attaining balance is interpreted in a graphical manner, which helps in the design and operation of the bridge. The diagrams show where to set the adjustments initially to get good sensitivity, and with which adjustment to start. Trivial balances, where the adjustments approach zero or infinity, are explained by the diagrams. Shifting balances, in which many adjustments are needed in order to approach balance, are shown to be present when the loci for the different adjustments intersect each other at angles less than about 45 degrees. The actual intersection angle can be obtained from the results of two partial differentiations of the balance equation, without the construction of the loci. From this angle, the rapidity of attaining balance can be found. Furthermore, it is shown that more rapid balance is obtained, especially with small intercept angles, if the adjustments are purposely overshot. Unfortunately, there seems to be a slight natural tendency toward undershooting.

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1. J. G. FERGUSON, "Classification of Bridge Methods of Measuring Impedances," *B. S. T. J.*, **XII**, 452, October, 1933.
2. For more detailed studies of locus diagrams, see J. L. LACOUR AND O. S. BRAGSTAD, "Theory and Calculation of Electric Currents," Longmans, Green and Co., 1913, Chapter III. Also, A. C. SELETSKY, "Cross Potential of a 4-Arm Network," *Elec. Engr.*, **52**, 861–7, December 1933.
3. A. C. SELETSKY AND L. A. ZURCHER, "Sensitivity of the Four Arm Bridge." Paper presented at the A. I. E. E. winter convention, New York, N. Y., January 23–27, 1939.

SENSITOMETRY OF PHOTOGRAPHIC PAPERS.

BY

LOYD A. JONES and C. A. MORRISON.*

(*Concluded from November issue.*)

NUMERICAL VALUES.

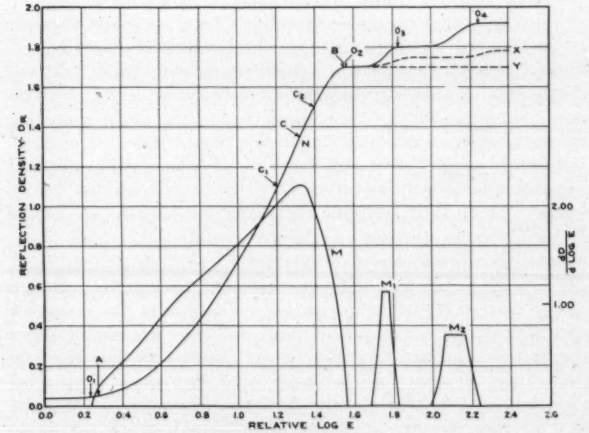
As stated in the introduction, it is desirable for many purposes to derive from the characteristic D-log E relationship certain numerical values which may be used for expressing the characteristics of these papers. In the introduction we reviewed briefly the nature of these numerical values and the definitions proposed for them in our earlier work. Experience accumulated on this subject during the years following the early work in this field has shown that some of the numerical values suggested at that time are of little significance and some of the definitions applied to these terms should be revised. There is little doubt that, in general, the shape of the D-log E characteristics of the developing-out papers commercially available have suffered an appreciable change since the first work on this subject. At that time practically all of the materials studied showed very definitely the existence of a region which, within the limits of the experimental error, was represented satisfactorily by a straight line and, in many cases, this straight line persisted over the major portion of the total exposure scale of the material. It must be admitted that at that time most of the sensitometric work was done on the basis of the time-scale exposures which, as we have seen, tends, at least under certain conditions, to enhance the straight-line relationship. However, curves determined by time-scale exposures on the papers available at the present time show definitely that straight-line relationships are much less frequently met and, when they are found, cover a smaller proportion of the total exposure scale. There seems to be little doubt that there has been a decided evolution in the development of these materials during the past twenty-five

* Communication No. 737 from the Kodak Research Laboratories.

years. Reference to information published on the characteristics of these materials in 1927 [3] and an actual rereading of some of the strips which have been preserved since the work was done prove to our own satisfaction, at least, that even in 1927 many of these materials exhibited *D*-log *E* relationships with greater straight-line propensities than those available today.

This undoubted general change in the shape of the *D*-log *E* relationship coupled with additional knowledge of the theory

FIG. 26.



Generalized density-log *E* relationship of photographic papers.

and practice of tone reproduction makes it necessary to propose a somewhat different group of numerical values as indices of the characteristics of developing-out papers. We shall now discuss in detail those values which we propose as being most useful in expressing numerically the characteristics of these papers.

In Fig. 26 the curve *N* represents in a generalized way the *D*-log *E* relationship for developing-out papers. It begins with a portion which is parallel to the log *E* axis. This repre-

sents the density due to development fog. When developing-out papers are processed according to the manufacturer's recommendations, they seldom, if ever, show any measureable development fog. However, if development is extended to long times, development fog may appear. In any case, it seems desirable to consider the most generalized form of this relationship as containing a region representing possible development fog. If we move along the curve through this fog region, where the gradient of the D-log E relationship is zero, in the direction of increasing exposure, a point, O_1, is reached which marks the end of the portion having zero gradient. At this point gradient begins to increase. The point A is located where the gradient, $dD/d \log E$, has reached a value of 0.20. From this point on, gradient (see curve M) continues to increase, reaching a maximum at the point designated at C. Here, gradient begins to decrease slowly at first and then quite rapidly. At the point B, the gradient has fallen until its value is again 0.20. From here it continues to decrease until at O_2 it is again zero. The point C is referred to as the *inflection point* and the gradient, $dD/d \log E$, at this point is designated as *maximum gradient*, $G_{max.}$. In some cases there may be a region, illustrated in the figure as that between points C_1 and C_2, in which the density-log exposure relationship is so nearly a straight line that departures therefrom cannot be detected by experimental technics. This may still be referred to as the straight-line region, but, since, in general, straight lines are not found, it may be better to refer to this region as the *inflection region*.

If we move along the curve again in the direction of increasing exposure, starting at the point O_2, we find that the density may increase somewhat, the gradient, curve M_1, in the meantime increasing to a maximum and then decreasing to 0 at the point O_3. The same thing may occur again, density increasing once more to a somewhat higher value, the curve flattening to another plateau, and the gradient, curve M_2, again becoming 0 at O_4. The region lying immediately to the right of the point O_2 may for convenience be referred to as the *extra shoulder*. The shape of the curve to the right of point O_2 is extremely erratic and in a certain sense unstable because, by repeated wettings and dryings of the sensi-

tometric strip, the relationship may change from that shown by the solid curve O_2 and O_4 to that shown by the dotted curve extending from O_2 to X and, in fact, by repeated washings or by washing in warm water, this region may be made to approach the line from O_2 to Y. When first observed, the behavior of the curve for exposures greater than O_2 was thought to be a result of uncertainties in density measurement. However, the work has been repeated many times using different types of density measuring instruments and the fact is now established beyond any doubt. In fact we have worked back and forth over this region, decreasing the exposure steps to $\Delta \log E$ intervals of 0.05 and even 0.025, and, in some cases, have made exposures on these materials using a *continuously* varying exposure and have then examined these developed strips in a continuously recording microdensitometer. All of these experiments verify the existence of the peculiar shape of curve shown in Fig. 26 to the right of O_2.

We are convinced that any density greater than that at O_2 is not effective for the reproduction of detail in prints. In the first place, the gradient of the curve has fallen to zero and continues at that value over an appreciable log E interval. Moreover, the study of the tone reproduction obtained under widely different conditions indicates that even the density at O_2 cannot, in general, be utilized for the effective reproduction of shadow detail. This has been shown by one of us.[12] In Tables VI to IX, inclusive, of that communication are given detailed numerical values showing the tone reproduction characteristics of a series of positives which are the best that can be made (by using the most appropriate contrast grade of printing paper) from a series of negatives which had been given a progressively increasing value of exposure. The developing-out papers used for making the reproductions had a density of 1.70 corresponding to the point O_2 in Fig. 26. The best possible prints* showed density scales on the average of 1.55 with minimum densities of approximately 0.05. Thus, the maximum density on the average in these excellent prints was approximately 1.60 or in a few cases

* Reference 12, pages 534–539, Nos. 8 to 12 inclusive of Tables XVI and XIX, and prints 7 to 12 inclusive in Tables XVII and XVIII.

possibly 1.65. In making these best possible prints, the negatives were printed on various contrast grades of the printing paper. When a higher contrast paper was used the density scale of the negative was then relatively great compared with the exposure scale of the paper so that a maximum density of 1.70 was obtained. The numerous judges who picked the best possible prints were almost unanimous in rejecting prints so made.

We feel that this is good evidence of the fact that a density corresponding to the point O_2 cannot be utilized in the making of high quality positives and, if this is true, it seems certain that higher densities in the region between O_2 and O_4 cannot be utilized. The gradient in this region not only is changing rapidly but is, on the average, low so that, in order to obtain the higher possible densities, such as O_3 and O_4, great density differences in the negative, corresponding to large brightness differences in the subject being photographed, would be required.

We have concluded, therefore, that the density corresponding to the point O_2 should be used as the most significant measure of the maximum density for these materials. This, of course, is not strictly maximum density because those at O_3 and O_4 are frequently higher. We do not feel justified in suggesting that the density at O_2 shall be referred to as the *effective* maximum density, because in many cases at least it cannot be utilized and because, as a matter of fact, it is not the effective practical maximum density. If it were necessary to distinguish between the densities occurring at O_2, O_3, etc., we should suggest that the density at O_2 be referred to as the *density corresponding to the second point of zero gradient.* However, there seems little need for setting up a terminology for taking care of this distinction and we propose to define as maximum density that corresponding to O_2. Unless a specific exception is made, the term *maximum density*, $D_{max.}$, as used in this discussion and in tables of numerical data showing the characteristics of developing-out papers, will be understood to apply to that density corresponding to O_2.

Speed.—The original expression of the speed of developing-out papers was made in terms of standard exposures, *ES*, the definition of which contained the phrase "just perceptible

density." The just perceptible density was not defined quantitatively. Since it seems desirable to modify this definition we have adopted for this purpose the exposure value corresponding to the point A on the curve (Fig. 26). The original formulation of standard exposure in terms of a density of 2.0 in the negative seems to have had little justification. We are suggesting, therefore, and have adopted for this purpose in these Laboratories, the following definition of speed:

$$\text{Speed} = 10^4/\log E_A,$$

where $\log E_A$ is the exposure, in candle-meter-seconds, corresponding to point A.

Maximum Gradient, $G_{max.}$.—This quantity is defined in terms of the equation

$$G_{max.} = dD/d \log E$$

at the point C.

Exposure Scale, ES.—This is defined as the distance, expressed in exposure units, between verticals drawn through the points A and B. It is frequently more convenient to express this in logarithmic terms, in which cases the quantity is designated as $\log ES$.

The possibility that exposure scale values determined in this manner may not always represent the *useful* exposure scale has been recognized. In a previous communication one of us has commented on this possibility as follows: *

"As stated previously, the total exposure scale of a positive material has usually been expressed in terms of the log exposure distance between the points having gradients of 0.20. More recent conceptions of the conditions leading to good tone reproduction raise the question of the utility of such exposure-scale values. It seems probable that the methods of defining *useful* exposure scale should be revised. . . .

"Evidence will be given later in this paper showing that the useful part of the characteristic curve is not limited in the low density region by a point having a fixed gradient. In view of these circumstances it may be wise to abandon the practice of expressing total *useful* scale as the distance between points having fixed gradient values. A definite recommenda-

* Reference 12, pp. 322 and 323–324.

tion for an alternative method cannot be made at the present time, but it seems reasonable to assume that the useful scale is limited in both the low and high density regions by points which have gradients which are some function of other gradient characteristics of the negative curve and of those of the positive on which the print is made. In any case it is quite certain that the gradient of the limiting point in the low density region is considerably less than that in the high density region, this conclusion being supported by the argument presented in previous paragraphs."

In spite of the possibility that the useful exposure scale does not always conform to the value of the exposure scale as defined in the first paragraph of this section, it seems certain that values determined as specified there are quite significantly indicative of the total exposure scale available and that this may be entirely utilized under certain favorable conditions.

Contrast.—As mentioned in the introduction, the problem of evaluating the contrast of photographic printing papers has been considered by several workers in the field of sensitometry. In a previous paper [3] we have taken the position that the total available contrast or *contrast capacity* of a photographic developing-out paper may be said in generalized terms to consist of two factors, namely, a *rate* factor and an *extent* factor. The rate factor depends upon the slope of the D-log E characteristic, namely, $dD/d \log E$, while the extent factor depends upon the density range of the paper.

In the quantitative evaluation of contrast, the position was taken that the integration of the gradient values should be in terms of density increments rather than in terms of exposure increments. The final evaluation according to these concepts takes the form

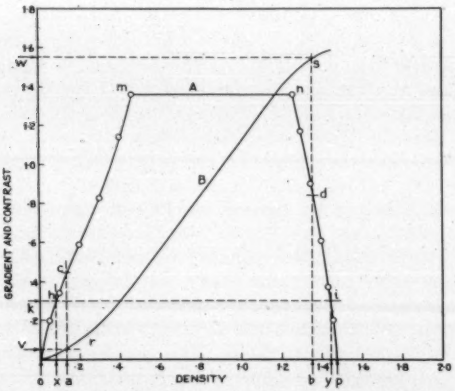
$$\Omega = \frac{(D_{\text{max.}} - D_{\text{min.}}) \cdot [\bar{G}(D)]}{l\Delta D^2},$$

in which $\bar{G}(D)$ is the average gradient computed in terms of equal density increments rather than in terms of equal log exposure increments, and $l\Delta D$ is the smallest density difference which the eye can discriminate under average print-viewing conditions, i.e., approximately equal to 0.007. For the detailed development of this formula and for the argu-

ments advanced in support of its validity, the reader is referred to the original publication.[3]

A graphic method of evaluating contrast according to the formula just given is illustrated in Fig. 27. The curve A is obtained by plotting values of dD/d log E as a function of the corresponding density, not log exposure. A measurement of the area enclosed by the curve A and the density axis now gives directly an evaluation of the contrast equation. It is

FIG. 27.



Curve A shows the relation between gradient, dD/d log E, and density. Curve B is the integral of curve A and shows directly the relation between contrast and density.

only necessary to choose proper units for plotting this curve and to make the proper setting of a planimeter in order to obtain directly the desired value. In computing contrast values, it is the practice in these Laboratories to limit the effective density scale between points A and B as indicated in Fig. 26. This assumes that the entire D-log E relation between these two points is effectively available for use in making prints.

It is necessary to discriminate carefully between the *contrast capacity* of a photographic paper and the contrast of a *utilized* portion. For instance, if, in making prints, conditions

are such that only a part of the available density scale of the paper is utilized, it is obvious that the contrast of the print may not be as great as might be indicated by a value determined by the technic indicated in the previous paragraphs. Again, prints may be made using a group of developing-out papers having different values of contrast (total available contrast or contrast capacity) which will have, according to direct judgments, equal contrasts. Under these circumstances it will be found that in making the prints, more or less of the available density scale has been utilized.

The formula for contrast just discussed was derived largely from theoretical considerations, but was supported by a considerable mass of statistical evidence. We did not at that time have available evidence which indicated conclusively whether equal increments in Ω corresponded to equal increments in the contrast of a series of developing-out papers as judged by direct psychophysical methods. When we began to apply this method of evaluating contrast to our sensitometric data, it was soon found that the relationship between values of Ω and the contrast number of a material in a series of similar developing-out papers was not linear. This is illustrated by curve *D* in Fig. 28 in which the ordinate values are those of Ω and the abscissa scale is established by placing the various contrast numbers of Velox *F* at equal intervals on the abscissa scale. Other groups of materials gave curves of similar shape which at once suggested an exponential relationship. We therefore tried plotting log Ω, with the result that the relationship shown in curve *B* for these same papers was found. The same relationships for the Kodabrom series and for the Azo *F* series are shown in curves *A* and *C*. It appears, therefore, that the contrast of a material as judged by the purely practical print method is directly proportional not to Ω but to log Ω. In defining contrast, therefore, if we wish to use this in a form which will be directly proportional to the practically observed facts, we should state that contrast is equal to log Ω.

Renwick [5] has noted that values of $\bar{G}(D)$, representing the rate factor of contrast in our formula, is proportional to the statistical judgments of contrast. This agrees, in general, with our observations that in order to obtain numbers which are

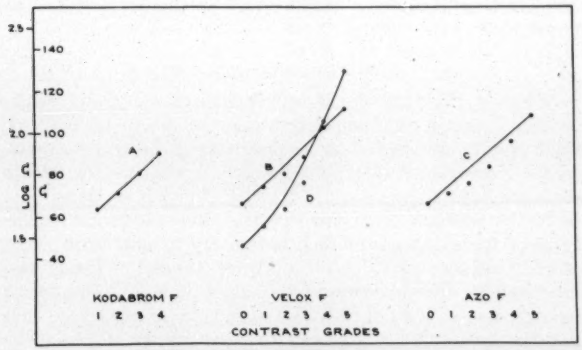
proportional to the contrast as evaluated by direct judgment, the logarithm of Ω must be considered. Renwick rejects our formula in favor of one of his own which involves only the average gradient determined by taking equal intervals *along the curve itself*. We still feel, however, that contrast in its usually accepted meaning involves not only a consideration of a rate factor, such as suggested by Renwick, but also of an extent factor which is determined by the density scale of the material.

The linearity for the four grades of Kodabrom is striking. Kodabrom is a photographic paper which was placed on the market a relatively short time ago. The emulsion makers in developing it attempted, with the assistance of expert judges of photographic quality, to develop four grades which were separated from each other by equal contrast steps. These workers were not familiar with the theoretical aspects involved in the evolution of the contrast formula. When contrast measurements were made on the material as finally evolved, it was found that plotting log contrast against the contrast grade gave a very satisfactory straight-line relationship. We feel that this is fairly satisfactory evidence that the contrast values, as determined by the proposed formula, are in good agreement with their practical evaluation. In curve *B*, Fig. 28, the same relationship for the six contrast grades of Velox *F* is shown and in curve *C* the same relationship for the six grades of Azo. The straight-line relationship is fairly good for the Velox materials and departs but little for the Azo material. It should be remembered, however, that in the case of the Velox and Azo materials all of the six grades were not developed by the emulsion makers at one and the same time. In the beginning, only four contrast grades of these materials were available. In response to the demand of the trade, additional contrast grades were developed and it is not surprising that under these conditions the equality of contrast step between adjacent grades is not as perfect as in the case of a group of papers, such as the Kodabroms, which were developed together as a group and designed specifically to have equal spacing on the contrast scale. However, even with the Velox and Azo materials as now manufactured, the

contrast spacing approached closely to a uniformity of steps as evaluated in terms of our contrast formula.

In view of all of this evidence on the significance of contrast values determined in this way, we consider it useful to adopt Ω as one of the numerical values for expressing the characteristics of these photographic papers.

FIG. 28.



Relationship of contrast Ω to designated contrast grade.

For the sake of clarity, we may summarize the series of numerical values, as follows:

Speed $(S) = 10^4/\log E_A$.
Log exposure scale $(\log ES) = \log E_B - \log E_A$.
Maximum density $(D_{max.}) = D$ (at point O_2) $-$ fog (D at point O_1)
Maximum gradient $(G_{max.}) = dD/d \log E$ at point C.
Contrast $= \Omega$.

$$\Omega = \frac{(D_{max.} - D_{min.}) \cdot [\bar{G}(D)]}{l\Delta D^2}.$$

In Table III are given values of these factors for the majority of the developing-out papers manufactured by the Eastman Kodak Co. The significance of the numbers in the first three columns is indicated by the column headings.

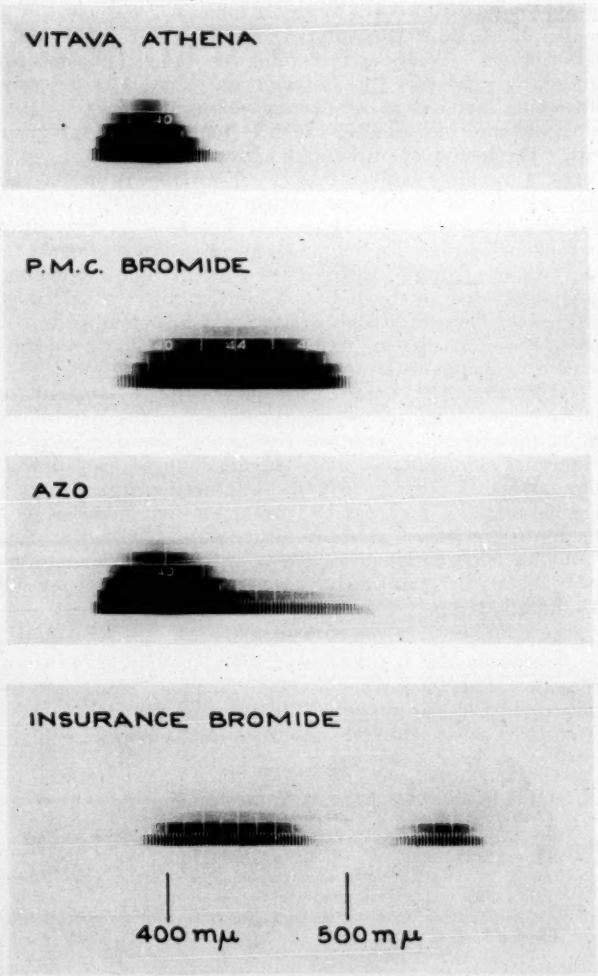
Under the caption "Maximum Density" will be found six columns, each headed by a number decreasing from 1.70 to 1.17. Under each of these are two columns, in one of which are given values of contrast (Ω) and in the other values of maximum gradient ($G_{max.}$). Below these are the letters designating the various surfaces of the papers. While the arrangement of this table may be a little confusing at first, a little study will familiarize the reader with its structure so that there will be little liklihood of misunderstanding the significance of the values.

SPECTRAL SENSITIVITY.

While in the narrower interpretation of the word "sensitometry," information on the treatment of spectral sensitivity is not usually included, it seems desirable at this time to make available some such information on this characteristic of the developing-out papers discussed in the previous sections. As the reader will have concluded by this time, modern developing-out papers depend for their sensitivity to light upon silver bromide, silver chloride, or mixtures thereof. These two silver halides differ considerably in their inherent response to various wave-lengths of radiation. In general, it may be said that silver chloride has a maximum of sensitivity at somewhat shorter wave-lengths than silver bromide. It is obvious, therefore, that there will be some difference in the distribution of sensitivity in the case of light-sensitive materials employing these two silver halides, and also, when used in mixture, a still different response to radiant energy of different wave-lengths will be found. Moreover, in the materials at present on the market, it will be found that additional sensitivity has in some cases been conferred on the product by the use of sensitizing dyes. If an individual determination of spectral sensitivity is made on all possible members of the developing-out paper group, a rather large number of different spectral sensitivities will be found. For approximate purposes, however, it seems satisfactory to group these materials into a relatively few classes for which spectral sensitivity curves may be given.

For certain purposes, spectral sensitivity may be most satisfactorily specified in terms of a curve showing the relationship between speed (expressed in appropriate terms) and

FIG. 29.



Several types of spectral sensitivity of photographic papers.

wave-length. However, for most practical purposes, it is sufficient to show this relationship by means of a wedge spectrogram. Wedge spectrograms are obtained in a spectrograph, over the slit of which has been placed a nonselective absorbing material whose density varies in a linear manner with distance measured in the direction of the spectrograph slit. The boundary of the dark area obtained after development of a sample exposed in such an instrument outlines approximately the curve representing the relationship between log sensitivity and wave-length. In Fig. 29 is shown a group of four such wedge spectrograms, each of which represents the approximate spectral sensitivity of a group of developing-out papers exposed to the radiation emitted by a tungsten incandescent filament lamp operating at a color temperature of 2800° K. Each spectrogram is so placed that its wave-length scale corresponds with others of the figure.

Warning.—The characteristic curves and spectrograms in the paper are designated by the type names of the materials to which they refer. It must be remembered, however, that the properties of commercial materials are changed from time to time and that consequently the information given as to a specific material may not be correct for that material as it occurs in commerce at some future date. On no account should the information given be used with the named materials as a means of quantitative measurement without specific confirmation.

ACKNOWLEDGMENT.

The authors wish to express their appreciation of the cooperation of Mr. Ray Wengel who designed and supervised the construction of the mechanical features of the optical-wedge intensity-scale sensitometer described in this paper.

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Whitney Wouldn't Know His Cotton Gin Today.—One hundred and forty-five cotton crops have been harvested since Eli Whitney invented the gin. Improvements in the machine began almost immediately after Whitney demonstrated it, and new parts, new attachments, and new processes have been added frequently since. The modern gin differs as much from the original—which was no more complicated than a kitchen meat grinder—as the present-day rotary printing press from the old screw press. A recent Farmers' Bulletin, Modernizing Cotton Gins, put out by the United States Department of Agriculture, gives a good idea of what the gin has come to be in these days when the American cotton crop runs from 12 to 18 million bales. A real up-to-the-times gin has a drier to put green, damp, or wet cotton into proper condition for ginning. There are seed elevators and various ways have been devised to keep seed pure so farmers growing a certain variety can keep it free of contamination by other seed. Not all of the more than 12,000 gins are modern, but hundreds of them have acquired the more recent improvements, including the seed cotton drier which, in the humid areas of the Cotton Belt, adds considerably to the value of the farmer's crop.

R. H. O.

Mining in Alaska in 1938.—Mines in Alaska produced minerals worth $28,607,000 in 1938, as against $26,989,000 in 1937, according to an announcement made by the United States Department of the Interior through the Geological Survey. The total value of the mineral output of the Territory since 1880 is $777,818,000 or much more than one hundred times the $7,200,000 paid to Russia for the entire Territory at the time of purchase in 1867. The value of the output of gold from Alaska mines in 1938 was more than a million dollars greater than in any other year in the entire history of gold mining in the Territory. The quantity of platinum metals recovered from Alaska mines in 1938 was much greater than in any preceding year and amounted to more than 88 per cent. of the total quantity of all platinum metals that have come from Alaska mines in all preceding years. In comparison with 1937 there was an increase in both the quantity and value of the production of gold, platinum metals, and coal; an increase in quantity, but a decrease in value of the production of lead; and a decrease both in quantity and value of the production of silver, copper, tin, and miscellaneous mineral products.

R. H. O.

THE VERMILYE MEDAL.*

At a reception and dinner held in Franklin Hall on the evening of Tuesday, November fourteenth, 1939. The Franklin Institute awarded the first Vermilye Medal to Mr. Lewis Herold Brown, President of the Johns-Manville Corporation, "in recognition of outstanding contribution in the field of industrial management."

After the reception, given by the officials of the Institute, the guests assembled in Franklin Hall, where the presiding officer, Mr. Philip Clayton Staples, President of the Institute, proposed a toast to Benjamin Franklin. At the end of the dinner, attended by a distinguished gathering of industrialists, bankers, and men prominent in civic affairs, Mr. Staples outlined briefly the policy of The Franklin Institute in awarding its medals and enumerated some of the outstanding scientists who had been honored in the past. He then pointed out that the Vermilye Medal covered a field hitherto unrecognized by such awards—that of industrial management.

As presiding officer he then introduced the donor of the medal, Mr. William Moorhead Vermilye, Vice-President of the National City Bank of New York. Mr. Vermilye stated that he had been led to establish the award by his own intimate knowledge of the fundamental importance of management in human affairs; and by his belief that the essentials of business are embraced in the three M's—Materials, Men, Management; that of these the greatest is Management. He stated further he chose The Franklin Institute to make the award because Benjamin Franklin was one of the first of the great Americans to be thoroughly management-conscious, and also because the Institute has been ever ready to acknowledge the achievement of men in the field of applied science, and that the recognition of business management as an applied science is a most important, if a somewhat novel, concept. He voiced his enthusiastic approval of the choice

* For an account of the founding of the medal see page 385 (September issue).

for the first award. The assumption of the trust in the name of The Franklin Institute was made by Dr. Henry Butler Allen, Secretary and Director.

Mr. Staples then called upon Mr. Edward Gowen Budd, a member of the Board of Managers of the Institute, who presented Mr. Lewis Herold Brown as the recipient of the award. He explained how the Committee on the Vermilye Medal had made its choice. He stressed the fact that this year the candidate was chosen for outstanding managerial ability in light of the social implications of the times, and expressed appreciation for the deep thought and effort given to their task by members of both the Advisory and Standing Committees.

He then presented Mr. Lewis Herold Brown to the President of The Franklin Institute, to receive the Medal.

The President bestowed the award and introduced Mr. Brown to the assembly.

Mr. Vermilye Mr. Staples Mr. Brown

PRESENTATION OF THE VERMILYE MEDAL

In accepting the Medal, Mr. Brown spoke as follows:

"In coming to Philadelphia this evening, I have been torn between two emotions—sincere appreciation for the honor you have so generously bestowed upon me, and some genuine discomfiture, in feeling that the *student* rather than his many *teachers* is being honored here tonight.

"No one could have been more surprised than I to receive word that such a distinguished organization as The Franklin Institute has singled me out to be the first recipient of this medal. That surprise became even greater on learning of the qualifications governing the award. As I listened to the

citation of achievements which we have just heard, I realized that in reality they are only the groundwork for the greater tasks that lie ahead, and there flashed through my mind an old Oriental proverb which says, 'Never predict what the day will bring forth until after the sun has gone down.' I hope I have not yet passed the noon-day period of my business career and that ahead lies at least 25 more years, before my sun goes down, in which to see completed many of the undertakings that have only just been started.

"To be so honored fills me, I assure you, with humility. Needless to say, I am deeply grateful. And in accepting this honor I hope that you will permit me to make at least one reservation to your committee's citation.

"It is not for any individual accomplishments, nor for anything that I personally may have done, that I accept the Vermilye Medal tonight. Instead I am here as one whom you have chosen to represent *all* of our business leaders, to

receive a tribute which honors the *spirit* rather than the isolated *deeds* of these men who direct American industry. In this role, I speak to you as a member of that new generation of business executives which is now taking its place upon the stage of industry and from which will come many who must assume their responsibilities as the business leaders of tomorrow.

"They take over in a period of grave uncertainties, with a sky dark and overcast. How they acquit themselves of the obligations that rest upon them is vital both to the future of industry and to the nation. Perhaps tonight I may be considered as speaking *for* them, as presenting *their* viewpoint, *their* estimate of the tasks ahead in the building of a better and finer America.

"If I may now put personal considerations aside for a moment, I should like to touch briefly on a point of broad significance which to me the awarding of this medal symbolizes; and that is the contribution which The Franklin Institute and Mr. Vermilye are making jointly to industry.

"Recognition for outstanding achievements has long been customary in scientific research, in the fine arts, in war, and in other fields of endeavor. These honors have done much to spur men to greater accomplishments. Now a new science of industrial management is being evolved, and this medal, thanks to Mr. Vermilye's vision and generosity, establishes it on a plane with the other arts and professions.

"It is both right and fitting that industry should be so recognized. It is a recognition that has been too long delayed. It helps to make amends for that great paradox which Miriam Beard emphasizes in her 'History of the Business Man.'

"Throughout all the great civilizations of the past, Miss Beard points out, the organizers of the *peaceful*—in contrast to the *warlike*—activities of men, are the great *Unknowns* of History. Soldiers and politicians have numberless monuments. Authors and artists leave personal records to posterity. But the men who pioneered the arts of *peace* remain nameless and unremembered.

"To that rule there is one notable exception—the man whose name this great institution reveres—Benjamin Franklin, statesman, yes—scientist, yes—philosopher, yes—but

with all these a businessman—one of the *first* businessmen of his time. We honor him not so much for his achievements, distinguished as they were, but because his was a *modern* mind—alert, practical, inquiring, always pushing back the frontiers of knowledge to take the next step which lay ahead.

"Today there is a clearer recognition, it seems to me, of the place which business occupies in modern society. There is growing understanding of the long-ignored fact that behind the billions of individual transactions which reflect the organized business activities affecting millions of people is an unseen balance wheel we now identify as management.

"The very complexities of the nation's industrial life have forced the evolution of a new type of business executive and the new profession of scientific management. The production of raw materials, their transportation to distant points for manufacture into the products of commerce, the distribution of finished goods to every city and hamlet in the land so that they are ready for daily and instant use—these are the province of business, and those who manage and direct it, while they are still called businessmen, are in reality the professional engineers of modern society. The public sees only the end result—it remains largely ignorant of the processes which make the result possible.

"The principles of this new profession of scientific management were largely codified by Frederick Taylor and Harrington Emerson early in this century. In 1911, Emerson said in discussing the principles, '(they) set forth a new view of the whole industrial problem. They define something infinitely greater than a system of management. They set forth a *morality* and provide practical measures for its attainment. . . . It is the declaration of a New Philosophy.'

"And indeed it was; for the work and writings of men like Taylor and Emerson and those who were to follow established *ideals*—a framework on which methods of operation, of human and social relationships in business could be based.

"Although still young in business, I have for 25 years been deeply interested in this new profession of scientific management, and from the analyses I have made from time to time of more experienced men's teachings I have set up in my own mind a few ideals which it seems to me we should

aspire to if we are ever to make this new philosophy a reality. These ideals blend into a composite man, if you will, whom I have attempted to describe on previous occasions in discussing this subject.

"What should be some of the characteristics that will distinguish this scientific manager, this business leader of tomorrow?

"First of all, it seems to me he will have to plan ahead with the vision of the engineer; he must estimate prospective income and expenditures with the exactness of the mathematician; he must be as receptive to advances in technical knowledge as is the research student in his laboratory. His knowledge of finance must approach that of the banker; he must be as keen a student of human nature as a psychologist; have the instinct of a teacher; the legal mind of an attorney; and the impartial attitude of a judge.

"Moreover, tomorrow's scientific manager needs to be a man with a keen sense of social responsibility. In this day of large corporations with thousands of employees and thousands of stockholders to consider, as well as the interests of customers and the public, he must have the sense of proportion and balance necessary to preserve and foster the rights and equities of all of these four groups.

"But perhaps the most important requisite is a flexibility and adaptability to ever-changing conditions. And I say this fully recognizing the need for a steadfast adherence to certain fixed and basic principles. Nevertheless, *change* is one of the principal themes of the modern world. He must hold himself flexible enough to readily meet these changes and adapt our industrial organizations to them. The present war is a striking example of the need for flexibility in our industrial system, for no one can foretell the events of tomorrow and the economic fluctuations to which business will be called upon to adjust itself.

"A great responsibility confronts these business leaders of tomorrow as they, in turn, must take over *old* problems left by a decade of depression and *new* problems created for American industry as a result of the present war in Europe.

"That war, with all its potentialities for our own possible involvement, has no illusions for American businessmen.

They know that war is such an easy escape from difficult domestic problems which still press insistently for solution, but which are quickly lost to sight when national passions are aroused. They know that it creates a fictitious stimulus to business, which brings in its wake new deflationary forces, new problems of readjustment and a crushing burden of debt and taxation. The myth that 'business promotes war' for its own profit has been at last exploded—let us hope forever!

"Far more important to American industry is the task of rebuilding a permanently prosperous America. To accomplish this, we face a three-fold responsibility:

"1. Work must be found for millions of our unemployed and genuine security re-established which is dependent upon jobs and not upon the payment of government benefits for idle men and idle land.

"2. The American enterprise system must be restored through applied scientific research and the stimulation of new business ventures to a basis where government spend-lend respirators can be finally and permanently dispensed with.

"3. The purchasing power of the public must be increased by continuing to produce more goods at lower prices, and by reducing the burden of taxation, which now consumes nearly a third of the national income, and would take more if we were on a pay-as-you-go basis.

"These are the basic problems that now confront us and that will continue to be the major challenges to tomorrow's leaders of industry. Only through their solution can this nation and its citizens re-establish their former standard of living that has been declining for almost ten years.

"And even as I say this, I can hear the voices raised of those who will not agree—those who have lost faith in our ability to help ourselves through work, resourcefulness and thrift, as well as those who will always attempt to sabotage our orderly progress by courting personal power through the despicable but none the less effective methods of inciting class hatreds and of sharpening with the whet-stone of Utopian dreams the desires of our people to override the laws of economics.

"I can hear the voices, moreover, of those who cry out

that our population will soon be static; that machines make labor unnecessary; that we can survive only by national economic planning; that we cannot bring government's expenditures within the limits of its income; that we can never permanently solve the relief and unemployment problems; that the hordes of Asia, accustomed to a low standard of living, will, given the advantages of the machine, overrun the world. In short that we are just another Roman Empire on our way to certain decline.

"As a realist and as one recognizing the emotional impact carried by alarmist statements, I nevertheless maintain that America and American industry are barely across the threshhold of their potentialities; that we have qualities of soil and climate second to none; that we have the best educated populace in the world; that American ingenuity which has brought us the world's highest standard of living is more than a match for brawn, and that, motivated by the spirit and principles which have given us the most successful form of representative government ever known, this country faces a future far more brilliant than its past.

"So it seems to me that our first and greatest task in solving the main problems that confront us is to set out courageously to *rebuild confidence in America*—a renewed confidence in ourselves. With this accomplished, there is no doubt but that trained leadership can and will guide us through to new heights of achievement.

"We cannot acquiesce in the defeatist philosophy that sees America as having passed its zenith of growth, as having become static and slowly running down like an unwound clock. We cannot accept the fallacious doctrine that the motive power for America's economic life can no longer be supplied through the initiative and the energy of a free people, but is now dependent upon an omnipotent centralized government. We cannot slam the door in the face of youth, saying to them cynically that opportunity has gone forever and that success no longer rewards those who are ambitious, thrifty and industrious.

"To adopt any such fatalistic attitude is to turn our back upon past accomplishments, to admit that we have become soft and without courage and that we are unworthy of our

great heritage! That is not the spirit which has made American business what it is. That is not the spirit of industry today, much less the spirit that will animate tomorrow's business leaders.

"Perhaps our present national inferiority complex is only a passing phase due in part to the sheer magnitude of our former achievements. Just remember that within the period 1900–1930, America created in industry, business, trade and other non-agricultural activities, *twenty million more jobs* than there had ever been before!

"The record of our past provides the challenge of our future. These achievements were the product of a dynamic people, restlessly energetic, who were never satisfied with an acceptance of the status quo. Each generation, impatient even of time's restraints, has torn down and rebuilt anew its cities, its homes, its factories, its highways, to conform to new ideas of usefulness, efficiency and comfort. Always the search has been for new and better ways of doing things —for new tools, new machines, new sources of power which would release men from drudgery and provide an increased leisure. The frontiers of the West have merged into a completely *new horizon*, and that horizon has no bounds except those of limitless faith in the future of a free and independent people.

"I would like to extend my thanks to you, Mr. Vermilye, to the members of the Advisory Committee on the Vermilye Medal, the Standing Committee on the Vermilye Medal, and to the officers and Board of Managers of The Franklin Institute for this great honor you have given to me and for this inspirational tribute to the field of Industrial Management. I am confident that business men all over the country are also deeply appreciative of this recognition of the importance of the profession of Business Management in our social structure.

"In accepting this award on behalf of the business leaders of tomorrow, many of whom in the years to come will in their turn be honored, I pledge you now that these men will have and will retain a limitless faith in the future of these United States of America, and of the ability of the American People to be Masters of their own Destiny."

Weather Bureau Adopts an International Code.—After nearly a half century of sending weather observations by coded words, the United States Weather Bureau has changed to the use of numerals. Beginning in July, weather observers in more than 200 cities are using combinations of the 10 numerals in sending their daily reports to the central office in Washington, D. C., and to other forecast centers. Although more than 10,000 coded words have been in use, a much better "picture" of weather at any station may be obtained with numerals. Almost any amount of information may be sent because, as with the use of words, the meaning of any number is changed by its position in the coded report The new arrangement keeps the United States in step with weather stations in other nations and in touch with ships at sea. Code messages in numerals are an international "language" and may be received and sent by stations all over the world. With the numbers code—for example—it is possible to report 99 different kinds of weather, 16 wind directions, more than 50 varieties of precipitation, about 30 cloud types, and about 10 deg. each of wind velocity and visibility, as well as barometer pressures and changes, temperatures, and other detailed weather information. Also, each weather station in the United States and Canada is now listed by an international index number.

R. H. O.

High Ceilings May Not Make Rooms Any Cooler.—Contrary to common opinion, engineering tests do not show that rooms with high ceilings are materially cooler in hot weather, and high ceiling rooms cost more and are harder to heat in winter. This conclusion is one of the results of a study of farm home construction in which the United States Dept. of Agriculture and the University of Georgia have been coöperating. The experiments included a pair of test houses in which the walls were of interchangeable panels, making it easy to alter the location and number of doors and windows and the height of ceilings, as well as the materials and conductivity of the walls. Thermometers on the walls and at various heights in the room did not show significant differences in favor of 10 foot ceilings as compared with 8 foot ceilings, when the same number and kind of windows were used in each test. A desirable arrangement of windows and doors to provide cross ventilation and to take advantage of the prevailing breezes did more to make the rooms more comfortable.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

SOLUBILITY OF GLASS USED FOR MAKING BOTTLES.

Comparison of the results of studies made by different laboratories on the determination of the solubility of glass used for making bottles and similar containers led to the conclusion that some of the inconsistencies found might be attributed to the methods used for titrating the "soluble alkali."

A study of the methods recommended or in current use was made by Donald Hubbard, E. H. Hamilton and A. N. Finn, who conclude that, all other conditions being equal, the method of titrating should be changed.

In this investigation the aqueous "extracts" of bottles were titrated with fiftieth normal acid, using the following indicators: Phenolphthalein, phenol red, brom thymol blue, methyl red, chlor phenol red, paranitro phenol, and methyl orange. At the same time that these titrations were being made the "extracts" were also titrated potentiometrically, using the glass electrode as the indicator. It was found that the disturbing effect of carbon dioxide absorbed by the "extracts" during their preparation and titration was great enough to vitiate results, especially when the amount of dissolved alkali was small.

Since the potentiometric titrations indicated that the effect of carbon dioxide should be eliminated, a series of "extracts" were acidified with a known amount of sulphuric acid, heated, boiled under reduced pressure, and "back titrated" with fiftieth normal alkali, both colorimetrically and potentiometrically, using the same indicators as in the "direct" titrations first used.

The results in "direct titration" varied from the true value of 5.50 ml by − 2.7 ml for phenolphthalein to + 0.2 ml for methyl orange, while the "back" titration the greatest differences found were − 0.7 ml for methyl orange and

* Communicated by the Director.

+ 0.15 ml for phenolphthalein. All other indicators used gave results which varied less than 0.15 ml from the true value.

It seems, then, that unless methyl orange is used as the indicator or the effect of carbon dioxide can be otherwise eliminated, acidification of the extract and "back" titration is to be recommended when one wishes to determine the amount of alkali dissolved from glass by water.

RELATIVE WEAR RESISTANCE OF CONCRETE FLOORS.

A portable apparatus for producing rapid wear of concrete floors, and an optical device for measuring the depths of wear, have been designed and built by L. Schuman and John Tucker, Jr. The apparatus, which is described in the *Journal of Research* for October (RP1252), consists essentially of three rotating steel discs moving in a circular path on the test surface.

Methods of testing have been developed for measuring the wear-resistance to depths of about 0.1 inch. A number of concrete slabs were made and tested, and the effect of such factors as mix proportions, water contents, time of troweling, dust coat finishes and liquid surface treatments determined.

Steel discs without the use of an added abrasive showed large differences in wear resistance near the surfaces of the slabs. This seemed to be related to the amount of water which appeared on the surface during placing and finishing. The wear with steel discs and added abrasive was useful in determining the resistance of the subsurface. For the same mix proportions, wear resistance was greatest for the highest cement-water ratios. For equal C/W ratios, wear resistance increased with increasing proportion of coarse aggregate up to a certain point, then decreased.

The mixes tested, which varied from a 1 : 2 mortar to a 1 : 3 : 6 concrete, all showed more or less pitting after the smooth surface had been worn off. The leaner mortars generally showed the greatest amount of pitting. The highest wear-resistance and least pitting were shown by the drier mixes, by mixes containing gravel, and by surfaces treated with dust coats containing cement, troweled into the fresh

surface. Damp-curing or the use of a high early strength cement increased wear resistance.

By means of the same apparatus it was also possible to study the dusting of surfaces. Dusting was reduced by surface applications of solutions of magnesium fluosilicate or of water-glass, where the mortar had not been damp-cured. The effect of such treatments appears to be confined to the top 0.01 inch of the slabs.

No significant reductions in wear were obtained by liquid surface treatments when applied to slabs damp-cured for 6 days.

METHODS FOR ESTIMATING THE CORROSIVITY OF SOILS.

The Magnolia Pipe Line Co. measured the depths of the deepest three pits on each joint of a 25-mile pipe line, and also estimated the condition of each joint. The resistivity of the soil was measured with a Shepard resistivity meter at 200-foot intervals. A soil survey of this line was made and several samples of each type of soil were obtained.

The pH values, total acidity, and electrical resistivity at saturation and at moisture equivalent of the soil samples were measured. The corrosivity of the soil samples has been determined by methods which include those devised by Corfield, Denison, Legg, and Putnam, and the results of these tests, as well as the corrosivity of the soil as indicated by its field resistivity, resistivity at moisture equivalent, and by its acidity, have been correlated with the depth of the deepest pit on the joints of pipe nearest the points where the samples of soil were obtained. The correlations are presented in the form of charts. They show that the result of a single test by any of the methods tried cannot be depended on to predict correctly the depth of the pit which may occur in the soil represented by the sample. However, if the data for all the samples from a soil series are averaged the results of tests by any one of several methods will give a satisfactory indication of the average corrosivity of the soil series.

It has also been shown that there is a reasonably close relation between the depth of the deepest pit on a joint of pipe, the estimated condition of the pipe, and number of leaks.

BACKFLOW PREVENTION IN OVER-RIM WATER SUPPLIES.

The danger of contamination of the water supply of buildings by the backflow of water from plumbing fixtures and drains, thereby menacing the health of persons using this water supply, has been receiving a great deal of attention from health authorities and officials in recent years. Numerous cases of disease, many of them causing death, have been traced to water that had been contaminated in this way.

It is not necessary that a direct pipe connection exist between the drainage and supply systems in order to bring about a dangerous condition. Toilet bowls with flush valves or tanks may be dangerous unless properly protected, since otherwise the occurrence of a vacuum in the supply line may produce a backflow of air from the toilet bowl, and the high velocity of this air flow may cause contaminated water to be carried from the bowl back into the supply line. Similarly, if a faucet opening is too near the water surface in a flooded lavatory, the occurrence of a vacuum in the supply line may draw water back through the faucet, if open or leaking, even though the faucet opening is not submerged.

In a paper entitled "Cross-connections in Plumbing Systems" (*J. Research N. B. S.*, **20**, 479 (April, 1938), RP1086), analyses were presented of the conditions under which backflow may occur in plumbing systems, as well as experimental data relating to these conditions. Building Materials and Structures Report BMS28, which has just been issued, is supplementary to RP1086 and contains the solution of a specific problem in this field, namely, the determination of the minimum requirements necessary to prevent backflow of the contents of an over-rim supply fixture, such as a lavatory, into the supply lines across a vertical air gap when a vacuum exists in the line.

This project, which was instituted by the Bureau, was carried to completion by the Plumbing Fixture Manufacturers Research Associateship which is sponsored by The Vitreous China Plumbing Fixtures Association, The Sanitary Cast Iron Enameled Ware Association, The Sanitary Brass Institute, and The National Brass Association.

The report deals principally with the technical phases of preventing backflow of water from over-rim supply plumbing

fixtures. It contains a discussion of past work on the subject, an analysis of the limiting values of the conditions that tend to cause backflow across air gaps, a determination of minimum requirements for the positive prevention of backflow through over-rim supply faucets under the extreme conditions that can occur, and suggested safety regulations which are presented in simplified form.

Copies of BMS28 are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

REFRIGERATION AND AIR CONDITIONING REQUIREMENTS OF PRINTING PLANTS.

Air conditioning is of great importance in the printing industry because atmospheric variations and extremes of temperature or humidity result in troublesome operating problems. Paper, the principal raw material used in printing, is very sensitive to atmospheric conditions, as are some of the other materials and processes. The variations and extremes, therefore, interfere with production and in many instances result in spoilage and lowered quality of the finished products. Symptoms of disturbing atmospheric effects are: Static electricity; misregister of color prints; ink set-off; distorted wood-block cutmounts; roller troubles; and distorted, curling, and buckling papers. An air conditioning system of correct design, if properly operated, will provide satisfactory solution of the problems involved by removing the causes of the disturbing effects. However, the atmospheric requirements of some of the processes of printing are exacting and each kind of printing has its own peculiar problems.

The principal processes of printing that require special consideration are: Multicolor offset lithography; all other sheet-fed processes including letterpress, sheet-fed gravure, wet-process color printing, and engraving; and newspaper and other web-fed printing. The conditioning requirements of each process and the degree of atmospheric control required for best results in each kind of plant are discussed in detail in an article by C. G. Weber of the Bureau's Paper Section,

published as a part of the Refrigerating Data Book by the American Society of Refrigerating Engineers.

The control of relative humidity is most essential, but control of temperature is also important. Central-station plants for conditioning the air of the entire building or the area used for the print shop have proved most successful and the dew-point system of control with refrigeration for dehumidification is applicable to all printing plants. This method of conditioning combines heating, ventilating, dust removal, and air conditioning in one system, and provides the required conditions throughout the year.

COSMIC RAY OBSERVATIONS IN THE STRATOSPHERE.

A paper by L. F. Curtiss, A. V. Astin, L. L. Stockman, B. W. Brown in the October *Journal of Research* (RP1254) describes an investigation of cosmic ray strength in the stratosphere by means of free balloons carrying a radio transmitter to send the measurements to earth, where they were picked up by a special receiving station. This was accomplished by using a sensitive tube circuit to detect the cosmic rays. A special vacuum tube circuit connected to the counter caused the radio transmitter to send out a signal for every 60 cosmic rays detected by the counter. This permitted the use of a large sensitive counter which counted cosmic rays at the rate of 2,000 to 3,000 per minute. In this way variations in the cosmic ray intensity, as a result of their random distribution in time, were leveled out and a more accurate estimate of their intensity could be obtained.

A barometer attached to the equipment gave measurements of the atmospheric pressure, simultaneously with the cosmic ray signals, to determine the altitude.

At an altitude of 64,500 feet it was found that the cosmic rays had a maximum intensity. Above this altitude they became less intense. The maximum was found to be about 200 times the intensity at the ground level. Observations were made up to 100,000 feet. A total of 15 ascents were made.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, NOVEMBER 15, 1939.

The regular monthly meeting of The Franklin Institute was called to order at 8:15 o'clock by Mr. Walton Forstall, Vice-President.

The minutes of the October meeting were approved as printed in the November issue of the Journal.

The Secretary announced that the additions to membership since the last report were as follows:

Sustaining	2
Active	13
Associate	13
Student	20
Total	48

The Secretary also called attention to the series of lectures which are to be held on alternate Friday afternoons during the winter and are designated as: "Meet Dr. Franklin." The next lecture on the seventeenth instant will be on "Dr. Franklin: Friend of the Indians," by Dr. Julian P. Boyd, Librarian and Editor of The Historical Society of Pennsylvania. An invitation was extended to the members of the Institute to attend.

The chairman then introduced Dr. Ellice McDonald, Director of The Biochemical Research Foundation of The Franklin Institute, who presented his Annual Report on the work of the Foundation. He gave an account of the activities of the Foundation and referred especially to: (1) study of the processes of disease from a chemical point of view, (2) study of new organic chemical compounds with regard to their therapeutic, medicinal and beneficent values, (3) study of longevity and the diseases of age, with the hope of prolonging the span of life. A short description was also given of the organization of the laboratory and its staff. The major and more popular aspects of the research were presented in a sufficiently non-technical talk to interest a general audience.*

After a brief discussion Dr. Meeker moved that a vote of appreciation be extended to Dr. McDonald and his staff for the accomplishments during the past year.

HENRY BUTLER ALLEN,
Secretary.

* See page 695 for complete report.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday November 8, 1939.)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 8, 1939.

MR. WILLIAM G. ELLIS *in the Chair.*

The following reports were presented for final action:

No. 3029: Duckbill Self-Loading Feeder Head for Shaking Conveyors.

This report recommended the award of Certificates of Merit to George H. Ernsbarger, of Honolulu, Hawaii, and Frank L. McCarty, of Rock Springs, Wyoming, "In consideration of the development of a simple, rugged and ingenious device for loading a jigging conveyor."

No. 3053: Contributions of Maxwell M. Upson to the Developments in the Manufacture of Concrete Piles.

This report recommended the award of an Edward Longstreth Medal to Maxwell M. Upson, of New York City, "In consideration of his contributions to the scientific development of foundation engineering and construction, characterized by genius for invention and technical skill."

At the May 10, 1939, Stated Meeting, the following report was presented for final action:

No. 3043: Hammond Electric Organ.

This report recommended the award of a John Price Wetherill Medal to Laurens Hammond, of Chicago, Illinois, "In consideration of the inventive skill displayed in the development of the Hammond Organ, a practical musical instrument for the production of tones of a wide range in pitch, intensity and quality by electrical means and for the combination and manipulation of these tones with the speed, certainty and flexibility demanded in the production of musical compositions."

This recommendation was advertised in the June issue of the Journal of The Franklin Institute and the advertisement has expired without the receipt of objection.

At the June 14, 1939, Stated Meeting, the following report was presented for final action:

No. 2985: Printing Telegraph Systems.

This report recommended the award of two John Price Wetherill Medals, one to Edward E. Kleinschmidt, of Highland Park, Illinois, and one to Howard L. Krum, of Beverly Hills, California, "In consideration of their part in the development of a successful electrically operated duplicate typewriting machine now known as the teletypewriter."

This recommendation was advertised in the July issue of the Journal of The Franklin Institute and the advertisement has expired without the receipt of objection.

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

The committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print $8\frac{1}{2} \times 11$ inches is forty cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 645 readers made use of the facilities during the twenty-six days of October.

RECENT ADDITIONS.

AERONAUTICS.

AHRENS, LOTHAR. Taschenwörterbuch, Flugwesen, Fünfsprachig. 1939.
Aircraft Year Book for 1939. Twenty-first Annual Edition.

ARCHITECTURE AND BUILDING.

American Concrete Institute. Proceedings. Volume 35. 1939.

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LAWSON, ROBERT. Ben and me. 1939.
Who's Who in Pennsylvania. Volume 1. 1939.

BIOLOGY AND BIOCHEMISTRY.

METCALF, C. L., AND W. P. FLINT. Destructive and Useful Insects. Second Edition. 1939.
RUPRECHT, KARL. Die Fabrikation von Albumin und Eierkonserven. Dritte, neubearbeitete Auflage. 1928.

CHEMISTRY AND CHEMICAL TECHNOLOGY.

ANDÉS, LOUIS EDGAR. Das Konservieren der Nahrungs- und Genussmittel. Zweite Auflage. 1916.
BENNETT, H. Standard Chemical and Technical Dictionary. 1939.
CONANT, JAMES BRYANT. The Chemistry of Organic Compounds Revised. 1939.
DAVIS, CARROLL C., AND JOHN T. BLAKE, Editors. Chemistry and Technology of Rubber. 1937. American Chemical Society Monograph Series. No. 74.
GANSWINDT, A. Das Färben der Seide. 1914.
GREGORY, THOMAS C. Uses and Applications of Chemicals and Related Materials. 1939.
HAEFCKE, H. Die technische Verwerthung von thierischen Cadavern. 1899.
HORATIUS, THEODOR. Die Fabrikation der Äther und Grundessenzen. Dritte Auflage von August Gaber. 1910.
JÜPTNER, V. JONSTORFF, HANNS. Die Untersuchung von Feuerungsanlagen. 1891.
KEIM, A. Die Mineral-Malerei. No date.

KOLLER, THEODOR. Handbuch der rationellen Verwertung, Wiedergewinnungen und Verarbeitung von Abfallstoffen jeder Art. Dritte Auflage. 1921.

KÜHL, HUGO. Lebensmittel. 1921.

LUHMANN, E. Die Fabrikation der moussierenden Getränke. Fünfte Auflage. 1922.

LUHMANN, E. Die Kohlensäure. Zweite Auflage. No date.

MAASS, O., AND E. W. R. STEACIE. An Introduction to the Principles of Physical Chemistry. Second Edition. 1939.

MACDOUGALL, F. H. Thermodynamics and Chemistry. Third Edition. 1939.

MERTENS, WILHELM. Das Sandstrahl-Gebläse im Dienste der Glasfabrikation. 1891.

MOORE, F. J. A History of Chemistry. Revision Prepared by William T. Hall. Third Edition. 1939.

RANDAU, PAUL. Die Fabrikation des Emails und das Emaillieren. Fünfte Auflage. 1925.

THOMSSEN, E. G., AND C. R. KEMP. Modern Soap Making. 1937.

WEBER, HAROLD C. Thermodynamics for Chemical Engineers 1939.

WERTHEIM, E. Textbook of Organic Chemistry. 1939.

WILFERT, ADOLF. Die Kartoffel- und Getreide-brennerei. Dritte Auflage von Wolfgang Wilfert. 1925.

DIRECTORIES.

Rubber Red Book. 1939.

EDUCATION.

COLEMAN, LAWRENCE VAIL. The Museum in America. Three volumes. 1939.

ELECTRICITY AND ELECTRICAL ENGINEERING.

CAMM, F. J. Television and Short-Wave Handbook. No date.

ENGINEERING.

MCKAY, ROBERT J., AND ROBERT WORTHINGTON. Corrosion Resistance of Metals and Alloys. 1936. American Chemical Society. Monograph Series No. 71

GEOLOGY.

UREN, LESTER CHARLES. Petroleum Production Engineering. Second Edition. 1939.

HISTORY.

JACKSON, JOSEPH. Encyclopedia of Philadelphia. Four Volumes. 1931–1933.

MANUFACTURES.

ANDÉS, LOUIS EDGAR. Praktisches Handbuch für Korbflechter. Zweite Auflage. 1920.

BÖCKMANN, FR. Das Zelluloid. Vierte Auflage. 1921.

CHWALA, AUGUST. Textilhilfsmittel. 1939.

MILLER, J. B. Glasätzerei. Fünfte Auflage. 1928.

MECHANICAL ENGINEERING.

CAMM, F. J. Practical Mechanics Handbook. No date.
HARTMAN, GERTRUDE. Machines and the Men who Made the World of Industry. 1939.
MORRISON, LACEY H. American Diesel Engines. Second Edition. 1939.

MINING ENGINEERING.

American Institute of Mining and Metallurgical Engineers. Transactions. Iron and Steel Division. 1939.
The Mineral Industry: Its Statistics, Technology and Trade during 1938. Volume 47. 1939.

NAVAL ARCHITECTURE AND NAVIGATION.

WHEATLY, WILKINS W. Square-Riggers before the Wind. 1939.

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American Annual of Photography, 1940. Volume 54. 1939.

PHYSICS.

BECKER, R., AND W. DORING. Ferromagnetismus. 1939.
HARRISON, GEORGE R. Massachusetts Institute of Technology Wavelength Tables. 1939.
HIBBEN, JAMES H. The Raman Effect and Its Chemical Applications. 1939. American Chemical Society Monograph Series no. 80.
JOST, WILHELM. Explosions- und Verbrennungs-vorgänge in Gasen. 1939.
KARELITZ, G. B., J. ORMONDROYD, AND J. M. GARRELTS. Problems in Mechanics. 1939.

POISONS.

MCNALLY, WILLIAM D. Toxicology. 1937.

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ELLENWOOD, FRANK O., AND CHARLES O. MACKEY. Vapor Charts and Special Tables for Turbine Calculations. 1939.

SUGAR.

O'NEIL, FRANCES. Candy Tricks and Treasures. 1935.
OWEN, WILLIAM L. Blackstrap Molasses as Raw Material for Biochemical Industries. 1939.
Sugar Reference Book and Directory. Eighth Annual Editlon. 1939.

TRANSPORTATION.

LANE, WHEATON J. From Indian trail to iron horse. Travel and transportation in New Jersey, 1620–1860. 1939.

NOTES FROM THE BARTOL RESEARCH FOUNDATION.

A NOTE ON THE NATURE OF THE PRIMARY COSMIC RADIATION.*

BY

THOMAS H. JOHNSON.

The existence of an east-west asymmetry in the cosmic radiation showing that almost all of the field-sensitive part of the intensity in the lower half of the atmosphere is produced by positive primaries,[1] raises some interesting points regarding the possible nature of the primary radiation. Swann [2] has pointed out what enormous potential differences would exist between relatively close points in interstellar space if any appreciable fraction of the radiation were unneutralized in the statistical sense. These potentials go up as the square of the distance and the calculation shows that if all of the primary rays are positive, potential differences between points at a distance of one light year would amount to as much as 7×10^{18} volts. It appears essential, therefore, that any theory must provide for a statistically neutral primary radiation. In a theory of the origin of auroral particles from the sun, Gunn [3] has presented a rather special mechanism by means of which a beam of charged particles could keep itself neutralized by drawing out charges of the opposite sign from the surrounding ionized atmosphere. It is unnecessary to consider the details of the process to the extent of Gunn's postulates, but merely assume that some means exists within

* Reprinted from the *Physical Review*, **54**, 385 (1938).

[1] The most recent estimates of the composition of the primary radiation based upon the asymmetry and the latitude effect leave but a small margin for negatives and the most probable result is that all of the field-sensitive intensity at sea level is due to positives. Defining $\beta \equiv (j^+ + j^-)/(j^+ - j^-)$, from the latitude effect we find $\beta = 1.16 \pm 0.50$ and from the north-south asymmetry $\beta = 0.8 \pm 0.30$. For first estimates see T. H. Johnson, *Phys. Rev.*, **45**, 569 (1934); **48**, 287 (1935); *Terr. Mag.*, **43**, 1 (1938).

[2] W. F. G. Swann, *Phys. Rev.*, **44**, 124 (1933).

[3] R. Gunn, *Terr. Mag.*, **38**, 247 (1933).

the atmosphere of a star or nebulum by means of which charges of either sign acquire an energy E of the order of cosmic-ray energies. After the emission has been going on for some time the source becomes charged with the opposite sign to a potential V determined by the condition that the initial particles when slowed down by loss of energy eV shall have the *same velocity* at infinity as the particles of opposite sign after the latter have acquired an equal energy eV. This is the necessary and sufficient condition for an equilibrium in which there is no space charge at infinity and a steady potential on the star.

Since the energies of positives and negatives whose velocities are equal are in proportion to their respective rest masses, a beam of heavy positives, such as protons, neutralized by negative electrons would constitute an apparently positive radiation at the earth's surface where the lower energy negatives are excluded by the magnetic field. It is not necessary to make any special assumption as to the sign of the charge which receives the original impulse for on this view the positive character of the radiation is a consequence only of the fact that more mass is associated with positive charge.

Whereas this interpretation of the primary radiation satisfies the asymmetry requirement and avoids the objectionable interstellar space charge, it does not account for the variation of the intensity with depth in the first layers of the atmosphere, for this is in agreement, as the balloon flights of Bowen, Millikan and Neher [4] have shown, with the quantum theoretical multiplication and absorption of a primary electron component of the energies dictated by the observed latitude effect. Ruling out the fantastic possibility of a positive electron radiation neutralized by a still lighter, and as yet undiscovered, negative particle, and accepting the premise that the first part of the ionization depth curve demands a primary electron component, the situation can be reconciled only by assuming the existence of two components of the primary radiation, the one consisting of positive and negative electrons in equal numbers and with similar distributions of energy, and the other composed of heavy positives, let us say

[4] I. S. Bowen, R. A. Millikan, and H. V. Neher, *Phys. Rev.*, **53**, 855 (1938).

protons, neutralized by negative electrons. Although the requirements would also be satisfied if the latter component contained positive barytrons (heavy electrons) neutralized by negative electrons, this hypothesis is not required since the barytrons in the atmosphere are already recognized as secondaries, and it does not seem likely that conditions exist in the universe where such a radiation could find its origin. In either case the east-west asymmetry must arise from a heavy positive primary radiation.

It is well known that studies of the absorption of cosmic rays near sea level have led to the identification of two types of secondaries, the hard component consisting of barytrons, and the soft component of positrons, negatrons and photons in equilibrium with one another. Our primary electron component has been invoked to give legitimate parentage to the soft component; it remains to establish the identity of the heavy positive primaries as the progenitors of the hard component secondaries. The fact that the asymmetry occurs at sea level demonstrates that the lowest energies of the heavy primaries contribute appreciably to the intensity in the lower half of the atmosphere. Indeed the asymmetry persists to a depth of at least two atmospheres, as is known from sea level measurements at zenith angles of 60°. While this is cogent evidence that the asymmetrical radiation comes down from the top of the atmosphere in the form of barytrons perhaps the strongest argument to this effect is found in the experiments [5] which showed that lead absorbing screens up to 30 cm. thick placed between the coincidence counters reduced the relative east-west difference by only a few per cent. and the first layers of the lead actually increased the asymmetry. Thus it was shown that the asymmetrical rays in spite of having been produced by primaries of the lowest energies actually belong to the more penetrating part of the radiation at sea level. Other experiments [6] made at a depth of six meters have shown that the soft component, which at that depth produces the major part of the showers, is almost completely symmetric, and while this does not necessarily point to an equality in the

[5] Experiments by S. A. Korff, B. Rossi and the writer have been summarized by the writer; see *Phys. Rev.*, **48**, 287 (1935).

[6] T. H. Johnson, *Phys. Rev.*, **47**, 318 (1935).

numbers of positives and negatives in the primary electron component, it does place the burden of the geomagnetic effects in the lower part of the atmosphere entirely upon the penetrating rays. As for the showers at sea level it is reasonable to suppose that many are produced by progeny of the penetrating rays, and it is not difficult to explain an asymmetry of the same order as that of the total radiation, such as was found [7] in shower experiments at the equator.

This identification of the asymmetry with the penetrating rays allows us to explain the fact that practically all of the sea level field-sensitive intensity in the lower part of the atmosphere is produced by primary positives by invoking the well-recognized fact that most of the intensity there is produced by the penetrating component, and it leaves the way clear for the soft component primaries to be made up of equal numbers of positrons and negatrons. Even though some small fraction of the intensity below six meters is produced by soft primaries, their energies required to reach to that depth would place them above the field-sensitive range.

Thus far our picture of the primary radiation has been built around the asymmetry, the transition effect at the top of the atmosphere and the demands for neutral interstellar space. If we now consider the fact brought out by Bowen, Millikan and Neher's balloon flights that by far the greater part of the primary radiation is electrically charged, the absence of an equilibrium intensity of photons seems to contradict the stellar origin introduced to provide a source of neutralizing particles, for but a few water-equivalent centimeters of absorbing matter would be required in the outer atmosphere of the star to give rise to as many photons as there are electrons. Their results have led the above authors to conclude that the rays are generated in vacuous interstellar space and that they have never passed through as much as a few centimeters of water equivalent matter before their arrival at the top of our atmosphere. Another alternative to this conclusion has been proposed by Alfvén [8] and it is more in harmony with the view developed here. He postulates a source of cosmic rays within our galaxy in which an equilibrium intensity of all types of

[7] T. H. Johnson, *Phys. Rev.*, **45**, 569 (1934).

[8] H. Alfvén, *Zeits. f. Physik*, **107**, 579 (1937); *Phys. Rev.*, **54**, 97 (1938).

radiation is generated. The photons, however, pass freely away from the galaxy and are lost in intergalactic space while the charged rays are retained and their intensity allowed to grow through the action of a galactic magnetic field. This view, although having to postulate a magnetic field, has the advantage that no unusual process need be envisaged for the generation of the energy of the cosmic radiation, since this would be quite small, nor for realizing the actual composition of the radiation. Thus the positron-negatron component would most naturally be regarded as a secondary product of the electrons or protons, whichever received the original impulse, having been generated as the latter were passing out through the atmosphere of the stellar source.

Summarizing, we suppose the existence of some unspecified process within the atmospheres of stars in which either electrons or positive ions are given an original impulse. As these pass outwards through the stellar atmosphere secondary positron-negatron pairs and an equilibrium intensity of photons are generated. The charge of the primary particles, being of one sign, raises the potential of the star to the point where opposite charges are repelled and both types of particles move along with equal velocities, the heavier particles having most of the energy. The secondary photons pass out into intergalactic space and are lost while the charged particles are retained by a galactic magnetic field. When these encounter the earth's field the positrons and negatrons pass through in equal proportion and constitute the soft component primaries. Of the other rays, only the heavy positives have sufficient energy to reach the earth's surface. There they constitute the positive primary radiation whose penetrating secondaries produce most of the intensity at sea level and below and account for the east-west asymmetry.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Seminar on Electrophoresis in Theory and Practice.—Dr. Arne Tiselius, Professor of Biochemistry at the University of Upsala, Sweden, conducted a seminar at the Biochemical Research Foundation on Tuesday afternoon, October tenth. He said he was happy to continue the tradition of interchange between the Biochemical Research Foundation and the Institute of Physical Chemistry in Upsala, and regretted that the political situation abroad necessitated curtailing both his stay in this country and his visit to the laboratory.

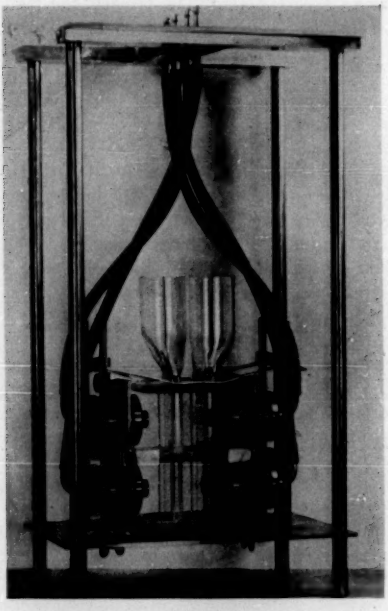
In addressing a group which was more or less familiar with the technique and potentialities of electrophoresis, Professor Tiselius felt it would probably be most worthwhile to emphasize the difficulties of the method and the ways in which they had been overcome.

The greatest difficulty encountered in all electrophoresis work is convection in the solution caused by passage of the current. To obtain the most favorable separation, the voltage should be as high as possible; but the heat developed by the current, which is proportional to the square of the voltage, gives rise to density differences which first distort and finally destroy the boundaries. In the neighborhood of + 4° C., where water and aqueous solutions have a density maximum, the variation of density with temperature is small. By keeping the solution at this temperature, and designing the U-tube to facilitate the transfer of heat from the solution to the thermostat, convection is reduced to a minimum. In this way it has been possible to increase the load 50–100 times, to 0.5–1.0 watt per cc., and to apply potential gradients about ten times as great as before.

The present design of U-tube consists of rectangular glass cells cemented between glass plates (Fig. 1); the sections of the tube can be moved laterally with respect to one another by means of pneumatic pistons, so that the contents of each section can be isolated. The lower half of the tube is filled

with the solution and moved out of alignment; the upper half is filled with a buffer solution of the same electrolyte composition. The large electrode vessels are attached (Fig. 2), and filled with the same buffer. When temperature equilibrium

FIG. 1.



U-tube portion of the Tiselius electrophoresis apparatus.

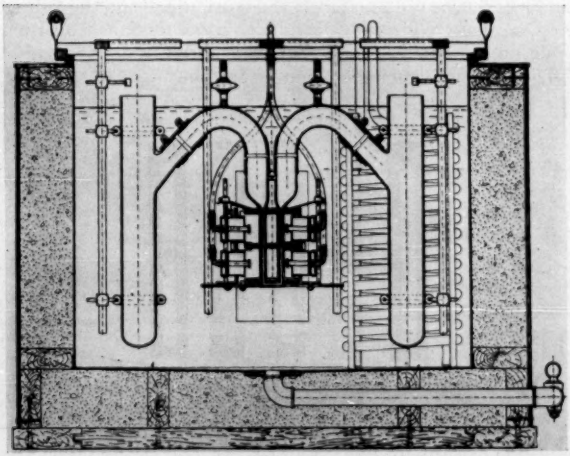
has been established, the lower section of the U-tube is moved back into alignment, and a sharp interface is created between solvent and solution. When the voltage is applied, the solute molecules move up in one side of the tube and down in the other.

The movement of the boundaries may be found by analy-

tically determining at the close of the experiment the quantity lost from one side of the tube and gained by the other. This, the transference method, is applicable to enzymes and other substances which have some property that can be readily assayed.

For most mixtures of proteins it is necessary to use optical methods because variations in chemical and physical proper-

FIG. 2.



The complete electrophoresis apparatus in the thermostat.

ties are not sufficient for differentiation. A method based on the refractive index gradient at the boundary, the Toepler schlieren method, permits direct visual observation during the experiment. The boundaries appear as black bands in the optical image of the cell (Fig. 3); the mobility can be calculated from the vertical displacement of the bands. Such measurements might be expected to give an accurate value for the mobility, but here another difficulty is encountered. Actually the movement of the boundary is not the same on

both sides of the tube because of the discontinuity in electrolyte composition at the original interface between solution and solvent, a result of the Donnan equilibrium which has been established during the previous equilibration by dialysis. Furthermore, the boundaries on the ascending side are migrating into a medium of buffer, while those on the descending side are migrating into protein solution. It has been shown theoretically by Henry and Brittain (*Trans. Faraday Soc.*, **29**, 789 (1933)) that more concordant values for the mobility can be obtained if on the descending side the voltage drop is calculated from the conductivity of the initial solution, while on the ascending side it is calculated from the conductivity of the advancing column of protein.

FIG. 3.

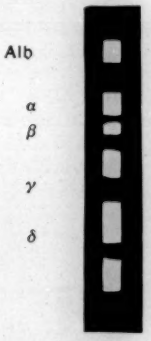
Electrophoresis of egg albumin observed by schlieren method.

The discontinuity can be minimized by the use of dilute solutions of protein and moderate concentrations of electrolyte, but frequently, as in the study of blood sera, higher concentrations of protein must be used if constituents present in low concentrations are to be observed. Under these circumstances the electrolyte discontinuity may be quite pronounced and may give rise in each tube to a boundary of very low mobility which is the result of the variation with concentration of the transference numbers of the ions.

The diagram for normal horse serum, diluted four times with a phosphate saline buffer solution of pH 8, is shown in Fig. 4. The fastest-moving boundary is that of serum albumin, the next three are of globulin fractions of different

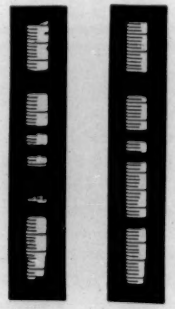
mobilities, designated alpha, beta, and gamma globulins, and the slowest is the delta boundary resulting from the electrolyte discontinuity mentioned above. Fig. 5 shows the dia-

FIG. 4.



The migrating boundaries of normal horse serum, schlieren method.

FIG. 5.



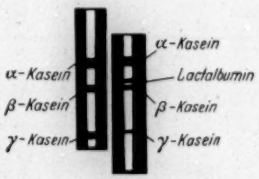
Electrophoretic schlieren photograph of unabsorbed (*a*) and absorbed (*b*) antipneumococcus horse serum.

gram for Type I antipneumococcus horse serum before and after removal of the antibody by precipitation with the homologous polysaccharide; the two diagrams are the same

except for the absence from the second of the broad band which represents the antibody. In all other immune sera so far studied the antibody has been found to migrate with the gamma fraction. In fact, even in Type I antipneumococcus horse serum, part of the antibody is associated with the gamma globulin if immunization of the animal has been continued for a long period.

Fig. 6*a* is the diagram for casein prepared according to Hammarsten's method; Fig. 6*b* is the diagram for milk. Both contain the three bands characteristic of casein, and milk gives in addition the band for lactalbumin; a fifth band due to lactoglobulin was also visible, but is not shown in the photograph. It can be seen from these diagrams that there

FIG. 6.



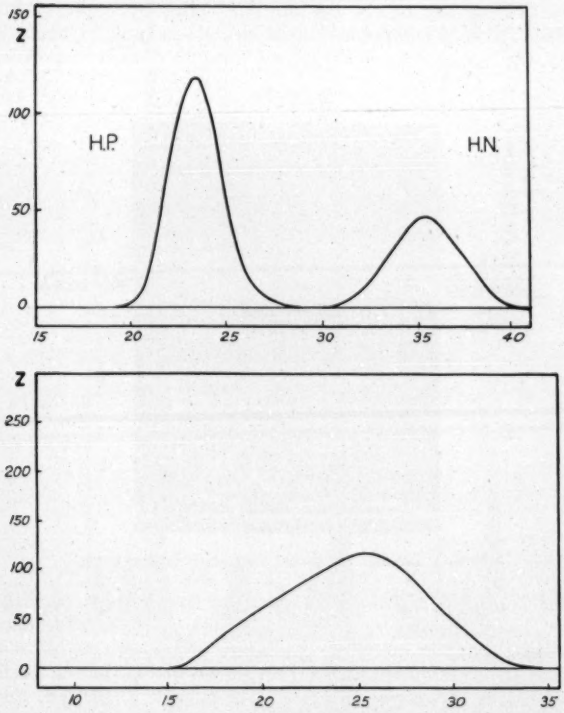
Electrophoretic schlieren photograph of casein (*a*) and milk (*b*).

is a certain analogy between electrophoretic analysis and spectrographic analysis. The former can be used in the fractionation of proteins to test for the presence or absence of a particular component in the same way that spectrographic analysis can be used to control the fractionation of a mixture of elements such as the rare earths.

Unpublished work on the digestion of egg albumin with pepsin has shown that in the hydrolysate a portion of the albumin migrates with unchanged mobility. There is a second band, representing the hydrolytic products, which migrates more slowly, but with remarkably uniform mobility; only slight separation is observed after prolonged passage of the current. These products have been isolated by electrophoresis and analysed; they are of low molecular weight, and probably consist of di- and tri-peptides exclusively.

Another refractometric method, the scale method of Lamm, makes possible the quantitative analysis of a mixture. The concentration gradient (determined by the displacement

FIG. 7.

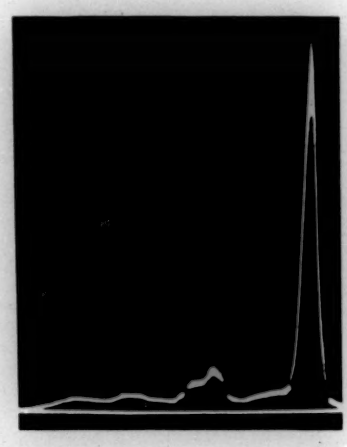


Electrophoretic diagrams, scale method, of mixed Helix pomatia (HP) and Helix nemoralis (HN) hemocyanins. (*a*) Native. (*b*) Dissociated at pH 8.5 and reassociated at pH 6.8.

of the lines of a ruled scale placed behind the cell) is plotted against the corresponding cell height (Fig. 7); the integration of the area beneath the curve gives the concentration.

Fig. 7 illustrates an interesting application of the electrophoresis method. The ultracentrifuge investigations of Svedberg have demonstrated that Helix hemocyanin, the respiratory protein of the snail, has a molecular weight of about 6,000,000 in the neighborhood of the isoelectric point. If the pH is raised to 8.5, the molecule splits into eighths; this dissociation is reversible, and if the pH is brought back to 6.8 the fragments recombine to form the whole molecule.

FIG. 8.

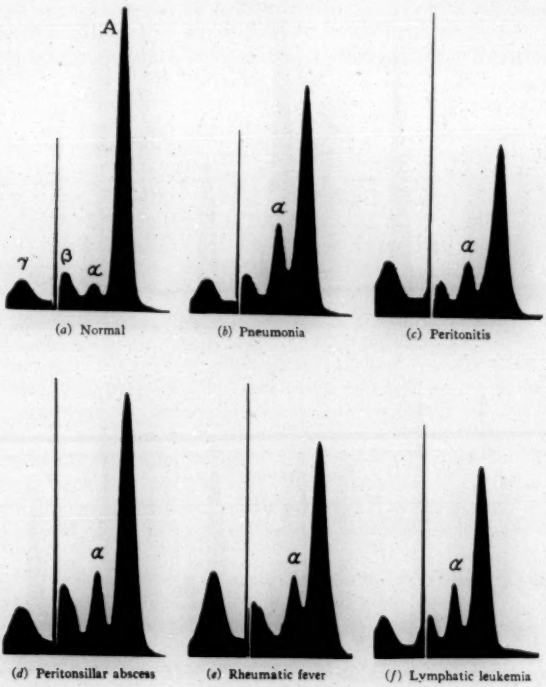


Electrophoretic diagram, Svensson method, of normal human serum.

The hemocyanins from two species of snails, Helix pomatia and Helix memoralis, though indistinguishable in molecular weight, differ in mobility; a mixture of the two at pH 6.8 gives the electrophoretic diagram shown in Fig. 7*a*. If each is brought separately to pH 8.5, then back to pH 6.8, the diagram is unchanged, while if the two are first mixed, then brought to pH 8.5 and back to pH 6.8, Fig. 7*b* is obtained. It is evident that mixed hemocyanins have been formed; the curve has approximately the shape which would be predicted for random combination of the fragments of one species with

the fragments of the other. Mixed hemocyanins are not formed unless the species are closely related. It thus appears that the forces holding together these giant molecules

FIG. 9.



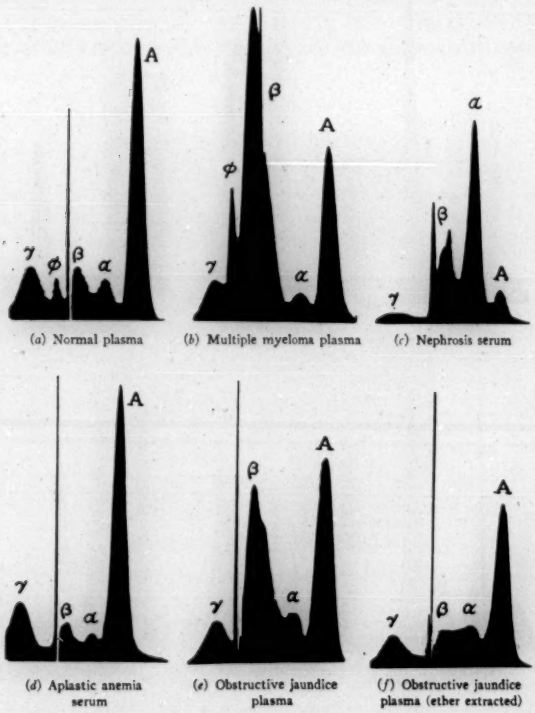
Electrophoretic diagrams, Longsworth method, of normal and pathological human sera. (Courtesy *Journal of Experimental Medicine.*)

are highly specific, of approximately the same degree of specificity as serological reactions.

The schlieren method has been adapted to give, automatically, diagrams of the same type as the scale diagrams.

One development, an optical modification, was originated by Philpot at Oxford, and improved by Svensson at Upsala; the other, a mechanical modification, was developed by Longs-

FIG. 10.



Electrophoretic diagrams, Longsworth method, of normal human plasma and of pathological human plasmas and sera. (Courtesy *Journal of Experimental Medicine.*)

worth at the Rockefeller Institute. Fig. 8 shows the electrophoretic diagram for human serum obtained by Svensson; Figs. 9 and 10 show diagrams for normal and pathological sera

and plasmas obtained by Longsworth and his collaborators. The patterns for normal serum and plasma are quite reproducible, but pathological sera and plasmas show large departures from the normal. In general a pronounced increase in alpha globulin has been observed in conditions accompanied by fever (Fig. 9). Other diseases, myeloma, nephrosis, and obstructive jaundice, have caused an increase in beta globulin, which, at least in the last two cases, appears to be related to high lipoid content (Fig. 10). Comparing the results indicated by these diagrams with the results of salt precipitation methods, it may be said that in normal serum the two methods give approximately the same figure for the albumin-globulin ratio, while in pathological sera salt precipitation methods are unreliable. The increased area associated with a given serum constituent in pathological conditions may not indicate a higher concentration of the constituent as such, but may result from the presence of some other substance of the same mobility; an example of this is the increase of gamma globulin after immunization of a rabbit with egg albumin. For this reason the isolation of the serum fractions so that they may be studied individually, both chemically and physically, to determine variations in disease and possible vehicle functions, is of immediate importance. It has already been found that bilirubin migrates with the albumin; the combination is broken if nucleic acid is introduced, and the bilirubin then migrates with the nucleic acid. The phosphatides are associated with beta globulin, the cholesterol largely with gamma globulin.

For isolation of the quantities of each constituent necessary for analyses of this sort, a larger type of electrophoresis tube has been developed which still permits optical control of the separation. This is built up of six to eight compartments instead of four, while the capacity has been increased from 11 ml. to 300 ml. The greater cross-section of the tube limits the voltage to about half of that which can be used in the smaller tube, but about five times the volume is separated in a given time. A special pipette, operated by suction and having a wide aperture closed with a porous disc, is used to remove samples at the close of the run so that the contents of a single compartment may be subdivided without disturbance.

The large electrode vessels required for such lengthy separations are too bulky to be handled as a unit with the U-tube and are therefore placed outside the thermostat. To use to the best advantage the separation capacity of the cell, clockwork compensation moves the solution as a whole through the tube in a direction opposite to the migration.

The question arises to what extent electrophoresis may be used to characterize a substance. Such characterization depends upon the variation of mobility with pH. For example, the polysaccharides are normally uncharged at all pHs so that they cannot be characterized, except as a group, unless they contain amino groups or acid groups which will give them mobility. However, because in general they do not migrate in an electric field, they can be separated from proteins by electrophoresis. Dr. Florence Seibert has taken advantage of this to prepare tuberculin polysaccharide from tuberculin.

Since the isoelectric points of most proteins fall within a narrow pH range, many proteins might be expected to have the same mobility at any given pH. An illustration that this can be so is afforded by a number of antisera, in which the normal gamma globulin is indistinguishable from the antibody at pH 8. However, the variation of mobility with pH is seldom the same for different proteins; and if two similar proteins are examined throughout the entire pH range, the mobilities are almost certain to differ at some pH. Landsteiner, Longsworth, and Van der Scheer have found slight variations in the mobilities of egg albumins from several species of fowl. As a rule the greatest resemblances occur between similar proteins from closely related species; but this is not invariably true, since hemocyanins from closely related varieties of snails can readily be distinguished, and Adair has found a distinct difference between foetal and maternal hemoglobin in sheep.

Theoretically it should be possible to distinguish two proteins even if the mobilities differ by very little. Actually the separation may be masked by the blurring due to diffusion, but since the effect of diffusion varies as the square root of the time, it should become less important as the time of separation is lengthened. There is, however, another factor which

limits the resolving power of the method: the spreading of the boundary independent of diffusion. This spreading can hardly be attributed to thermal disturbance because it is reversible if the current is reversed. It can be seen most strikingly in the migration of the hemocyanins, which, because of their huge size, diffuse very slowly. Either the protein consists of a number of stable forms which differ slightly electrochemically, or an unknown source of disturbance occurs in the electrophoresis experiments.

The formal presentation of the subject was followed by discussion. When asked whether the alpha, beta, and gamma globulin fractions had been tested serologically, Professor Tiselius explained that this has not yet been possible because of the difficulty of separating sufficient quantities of these fractions. Fibrinogen has not yet been isolated electrophoretically; its low concentration in the plasma and its unfortunate situation between beta globulin and gamma globulin, very close to both, make the separation exceedingly difficult. The sharp boundary with which fibrinogen migrates in the plasma indicates that a much finer product might be obtained by this method; chemical separations yield fibrinogen which migrates with a diffuse boundary and is probably partially degraded.

Dr. Ellice McDonald expressed surprise at the orderly manner in which the peptic hydrolysis of egg albumin proceeds, and the low molecular weights of the end-products. Professor Tiselius replied that pepsin had been selected for the investigation because the proteolytic action of this enzyme is less extensive than that of a number of other proteases such as trypsin; he had hoped that pepsin would scale off the peptides one by one so that the hydrolysis might be followed step by step; but it appears instead that any albumin molecule which is attacked is completely broken down into di- and tri-peptides. Dr. K. A. C. Elliott suggested that the molecule of egg albumin may remain adsorbed on the surface of the pepsin until it has been completely digested, and that it can be replaced by a second only after release of the end products. He suggested, too, that while adsorption of the substrate could not be demonstrated with proteolytic enzymes because the proteolytic reaction would interfere with

the stability of the boundaries, it might be demonstrated with certain oxidizing enzymes in the absence of their coenzymes, because combination between enzyme and substrate would not be followed by reaction.

In answer to the suggestion by Mr. Thomas Dietz that it might be preferable to carry out electrophoretic experiments with undiluted, rather than diluted, serum, the statement was made that dilution of serum has not been found to cause changes in electrophoretic behavior, though it does cause changes in particle size which have been detected by means of the ultracentrifuge. When whole serum is allowed to migrate into 9/10 diluted serum, the same constituents are observed as in 1/10 diluted serum, and in the same concentrations. Although in ultracentrifuge measurements with slightly diluted serum it has been observed that the substitution of phosphate buffer for Ringer solution causes further dissociation of the X (or beta globulin) fraction, the removal of electrolytes from serum by dialysis against phosphate buffer has not been found to influence materially the electrophoretic pattern, though small changes may possibly occur. Concerning the stability of serum on standing, it was stated that frozen serum can be stored for some time without alteration of behavior in electrophoresis and sedimentation.

(Reported by Laura E. Krejci.)

The Purification of p-Acetaminobenzenesulfonyl Chloride.—L. H. PENCE AND H. C. WINTER (*Journal of the American Chemical Society* **61**, 2977 (1939)). The discovery of the therapeutic value of sulfanilamide in the treatment of bacterial infections has given impetus to the investigation of a great number of compounds related to it. The important intermediate used in the synthesis of these compounds is p-acetaminobenzenesulfonyl chloride, which reacts with various amines to give the corresponding sulfanilamide derivatives. Investigators in this field, however, have been inconvenienced because of the lack of a suitable method for purifying large quantities of the sulfonyl chloride. It is essential that the intermediate be purified immediately after its preparation, since the compound readily decomposes when it is allowed to stand in the crude state. The least satisfac-

tory part of its preparation, unfortunately, has been the purification. This was a distinct disadvantage when storage of appreciable amounts of the intermediate for future use was desired. A convenient method for purifying large quantities of the acid chloride is therefore a welcome improvement.

Smiles and Stewart (*Organic Syntheses*, **V**, 3 (1925)) used benzene as the solvent for the recrystallization of the 90 g. of crude sulfonyl chloride obtained by their procedure. Since the product will dissolve in benzene only to the extent of 2 per cent. when hot and 0.5 per cent. cold, giving a 70 g. yield of pure p-acetaminobenzenesulfonyl chloride, they have stated that the recrystallization of more than a small amount of the compound at one time is not practical.

In the present paper a new modification is given which is an improvement over the former method for the purification of large amounts of the sulfonyl chloride from the standpoints of both time and convenience. After starting with the quantities and procedure suggested by Smiles and Stewart (acetanilide (67.5 g.) and chlorosulfonic acid (290 g.)), the crude, precipitated p-acetaminobenzenesulfonyl chloride is obtained on pouring the reaction mixture into crushed ice. The crude solid is separated by centrifuging and washed three times with water. The damp precipitate is dissolved in ether (1000 cc.), and the latter washed in a separatory funnel with four 50 cc. portions of water. The last portion of wash water is then free of sulfate ion. After drying the ethereal solution for one hour over anhydrous sodium sulfate the drying agent is removed by filtration. Longer drying is to be avoided to prevent the precipitation of the sulfonyl chloride, since the latter is less soluble in dried ether. The ethereal solution is concentrated to 300 cc., at which point the acid chloride begins to crystallize out, and benzene (1000 cc.) is added. After cooling to 0°, the crystals are filtered off by suction, washed with benzene, and dried *in vacuo*.

The average yield of several preparations of the colorless crystals of p-acetaminobenzenesulfonyl chloride was 70 g., melting at 149°. The melting point of an earlier preparation (m.p. 148°) remained unchanged after the compound stood for seven months.

Studies on Capsule Formation. I. The Conditions under which Klebsiella pneumoniae (Friedländer's bacterium) Forms Capsules.—J. C. HOOGERHEIDE. (*Journal of Bacteriology*, **38**, 367 (1939.) Several species of bacteria, especially pathogenic bacteria, are characterized by the possession of slimy envelopes, usually called "capsules." These capsules seem to play a definite role in the pathogenicity of the bacteria, acting as an armor to protect the bacteria against the unfavorable conditions, e.g. phagocytosis, to which they are exposed in the host. Thus they can maintain themselves under conditions which eliminate non-encapsulated variants.

A considerable amount of work has been done to find out the chemical nature of these capsules and the serological reactions of the capsular substances. Little if anything is known however about the conditions under which this protective coating is synthesized by the bacterial cell. The present paper is a first attempt to obtain a better insight into this process of capsule formation by pathogenic bacteria. Klebsiella pneumoniae (Friedländer's bacterium), the causative organism of a certain type of pneumonia, was chosen to be studied.

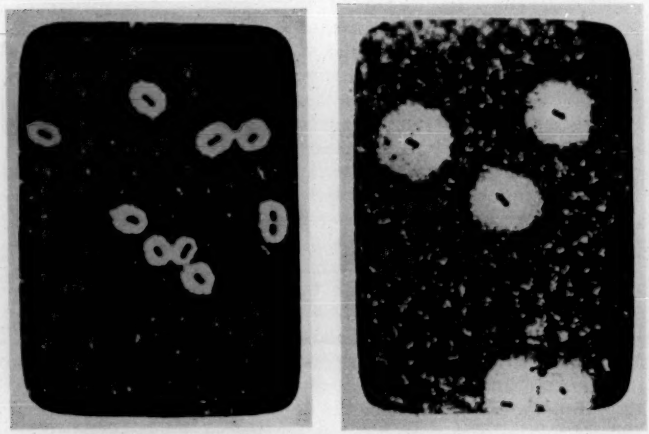
This organism may develop enormous capsules as may be seen from Illustration 1. In order to be able to compare the average capsule sizes under different conditions a new method had to be worked out. For the organism used, this problem could be solved satisfactorily by measuring the relative viscosity and doing a cell count at the same time during growth of the organism in the usual Ostwald viscosity meters. When no capsules are formed, practically no increase in viscosity of the culture takes place during growth. When the bacteria are well encapsulated, however, the relative viscosity increases very rapidly. Curves were made in which the relative viscosity observed was plotted against the number of bacteria per cubic centimeter responsible for this relative viscosity. By comparing such curves, definite conclusions could be drawn as to differences in average capsule sizes.

By applying the new technique it was found that capsules, when present, can be removed easily from around the bacterial cells by submitting a suspension of encapsulated bacteria to a short treatment (2–3 minutes) with ultra-sonic

waves. Such a short treatment does not destroy the bacterial cell but brings the capsular substance into solution.

Capsular substance appeared to be synthesized to an appreciable extent (from glucose, saccharose, maltose, mannitol, pyruvic acid, glycerol, rhamnose and salicin), only when fermentable carbohydrates were present in the nutrient medium.

FIG. 1.



(*a*) Encapsulated Friendländer's Bacterium from a 4 per cent. neopeptone-1 per cent. glucose culture (3 hours after incubation).
(*b*) The same culture 7 hours after incubation. (Courtesy *Journal of Bacteriology*.)

The nitrogen source in the medium was found to be of equal importance, however, for good encapsulation. The usual bacteriological peptones, such as Bacto-, Neo-, or Witte peptone, combined with glucose, made excellent media for abundant capsule formation. On the other hand yeast-extract, brain heart infusion, bacto-tryptone, though furnishing excellent media for growth of the bacteria, suppressed encapsulation very markedly. Addition of a buffer (bicarbonate or phosphate) did not influence encapsulation, but since growth was enhanced greatly, extremely viscous cultures

could be obtained. From such cultures good yields of capsular substance were obtained.

Good encapsulation was obtained also in a synthetic meduim, in which the only nitrogen source was asparagine. Under such conditions, however, capsule formation proved to be very delicate inasmuch as good capsules were formed only when the phosphate concentration of the medium was so low as to limit bacterial growth.

Evidence could be obtained that capsules are formed after the logarithmic phase of growth, under conditions which are unfavorable for growth. Capsule formation in vitro seems to be a protective measurement against unfavorable conditions.

The Evaluation of Germicides by the Manometric Method. —J. O. ELY. (*Journal of Bacteriology*, **38**, 391, 1939.) The most commonly used method for testing and standardizing disinfectants is the phenol coefficient method. The phenol coefficient of a germicide is obtained by dividing the figure indicating the degree of dilution of the germicide that kills an organism in a given time by that figure expressing the degree of dilution of the phenol that kills the same organism in the same time under exactly similar conditions. Because the method requires much time and labor the need for a simpler method requiring less time is recognized.

Manometric methods have shown that germicides exert an inhibitory effect on the respiration of bacteria. It has been suggested that the degree of inhibition of the respiration of organisms, as determined by manometric methods, might be a very useful and satisfactory substitute for the phenol coefficient method in determining the values of a germicide. Values obtained by the use of a new substance could be compared easily with those obtained with a standard phenol solution.

As with many new methods, questions frequently arise as to the true value of the results obtained. Several questions relating to this new method have been investigated. Escherichia coli was selected as the test organism. The oxygen consumption of suspensions of the bacteria was measured by the use of Warburg manometers.

The first question considered was the relation between the inhibition by germicides of the oxygen consumption of the bacteria and the subsequent ability of these organisms to grow when subcultured. The results indicate that so long as the bacterial suspension shows any trace of oxygen consumption viable bacteria are present. All of the organisms in a suspension have been killed by a germicide only when the oxygen consumption has been reduced to zero. It was found that the inhibition of respiration may be nearly complete, but positive subcultures still would result. The assumption was made that all of the organisms were killed when the oxygen consumption was reduced to zero. This assumption was confirmed by subjecting a suspension of E. coli to merthiolate in a dilution of 1 : 24,000, measuring the oxygen consumption and making subcultures at successive 15 minute intervals. At the end of a 15 min. period subcultures were positive if the oxygen consumption was still evident during the period, but negative if the oxygen consumption had been zero during the period.

The effect of several germicides on oxygen consumption in relation to time was studied. It was found that the percentage inhibition caused by germicides increases with time until a maximum is attained. If the inhibition of respiration was 100 per cent. the culture was dead; but when the maximum was less than 100 per cent. the percentage inhibition did not recede from this maximum during successive half-hour periods of time except in small amounts which might be ascribed to experimental error.

The relation between the amount of inhibition of respiration of a bacterial suspension caused by a germicide and the relative number of the organisms killed appears to be very important if comparisons of germicidal activity are to be made on the basis of inhibition of respiration.

It was found that in 15 min. in a 1 : 128,000 dilution of merthiolate in salt solution a suspension of bacteria showed an inhibition of 61 per cent. in respiration while there was a 43 per cent. reduction in the number of living organisms with reference to the control suspension. However, under similar conditions a 1 : 120 dilution of sulfanilamide inhibited respiration by 55 per cent. but none of the bacteria was killed.

Data show also that with merthiolate in a concentration sufficient to cause a marked inhibition of respiration there is a relatively greater percentage of the organisms killed in relation to the inhibition of respiration than there is with a lower concentration of merthiolate which produces a lower inhibition of respiration. For example, a concentration of merthiolate in a salt solution showed a 61 per cent. inhibition with a reduction in the number of living organisms of 43 per cent. while in rabbit serum a concentration of 1 to 9500, causing an inhibition of 33 per cent. in the respiration caused the death of only 7 per cent. of the organisms. Thus it seems apparent that the relation between the percentage of inhibition caused by germicides and the relative number of organisms killed may vary not only with the germicide used but also with different concentrations of the same germicide.

It is known that most germicides are not as effective in the presence of serum as when in salt solution. Manometric measurements of the inhibition caused on suspensions of E. coli in a salt solution and in rabbit serum showed a very marked decrease of the effectiveness of tincture of iodine, merthiolate, and sodium-o-phenyl phenate when in the presence of serum. For example, tincture of iodine killed a culture completely in 15 min. in salt solution whereas in serum the same concentration caused only a 74 per cent. inhibition of respiration over a period of 30 min.

In contrast to the above mentioned germicides the action of sulfanilamide was unaffected by serum. The action of formaldehyde and of phenol was found in each case to be reduced by serum to a very much less extent than was that of merthiolate and tincture of iodine.

Because of the differences in the ratio of the amount of inhibition of respiration to the amount of killing caused by different germicides and by different concentrations of the same germicides, it is thought that further studies of the method must be made before it can replace the phenol coefficient method.

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